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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1955 WINTER MEETING ON THE PACIFIC COAST

AT

THE UNIVERSITY OF SOUTHERN CALIFORNIA

December 28, 29, and 30, 1955

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BULLETIN

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AMERICAN PHYSICAL SOCIETY

1955 WINTER MEETING AT THE UNIVERSITY OF SOUTHERN CALIFORNIA, DECEMBER 28, 29, AND 30, 1955

THE **1955 Winter Meeting on the Pacific Coast** of the American Physical Society will be held at the University of Southern California on Wednesday, Thursday, and Friday, **December 28, 29, and 30, 1955.** This meeting is being held in connection with the 75th anniversary of the founding of the University of Southern California. In view of the occasion, President F. D. Fagg, Jr., will deliver a message of greeting to the American Physical Society at the banquet of the Physical Society on the evening of Thursday, December 29. His address of welcome will be followed by a talk by President L. A. DuBridge of the California Institute of Technology. The title of the speech is "Physicists Wanted." The presiding officer will be President R. T. Birge.

There is nothing unusual about the size of the programme. There are 33 invited papers and 96 contributed papers. This has led to seven sessions of invited papers and ten sessions primarily of contributed papers. The somewhat higher than normal number of invited papers is due to the lucky opportunity to arrange, at the last moment, a symposium on the anti-proton. The symposium is listed as Session K of this programme, Thursday afternoon at 2:45, in 133 Founders Hall. In the anticipation that the session will be somewhat better attended than most, it has been decided to have no other papers after 2:45 on that afternoon. This necessitated some distortions in the time schedule in the rest of the programme, for which indulgence is begged.

The Division of Electron Physics is represented on the program by a symposium of four papers on Wednesday afternoon (Session D). The program was arranged by W. P. Dyke. The Division of Solid State Physics is represented by a symposium of five papers on the program on Friday (Session L). This program was arranged by C. Kittel. In addition, we have further to thank J. R. Richardson for a programme in High Energy papers (Session A), R. F. Christy for one in Theoretical Physics (Session E), C. D. Anderson for one in Cosmic Rays and K-Mesons (Session O), and C. H. Eckart for one in Physical Oceanography (Session G).

The physical arrangements for this meeting are excellent because of the fine facilities of the University of Southern California and the excellent preparations of the Chairman of the Local Committee, Professor G. Weissler. **Registration** will take place in the lobby of Founders Hall on the campus. This is the same building which contains all the lecture halls that have been reserved for the use of the Society. Members and guests will be asked to pay a registration fee of $1. As usual, a telephone and message board will be available at the registration desk. In addition, rooms will be set aside for informal discussions for members of the Society and also for the purpose of interviews by prospective employers.

There is no official hotel for the Society. However, the **Biltmore Hotel** in downtown Los Angeles has kindly set aside rooms for the use of members of the American Physical Society. Members needing special accommodations, such as local hotels or motels, will find their purposes best served by writing directly to the Chairman of the Local Committee. For those members of our Society who are unfortunate enough to have to travel from downtown Los Angeles to the campus by public transportation,* the following is the recommended method. It is best to take westbound streetcar lettered "J", at 7th Street between Grand Ave. and Broadway and alight at the intersection of Jefferson Boulevard and University Avenue. One-half block from the streetcar is Founders Hall, and there should be no difficulty in finding it, since arrows will be placed giving directions. Maps of the campus will be available at the registration desk in

* The Secretary of the Society would prefer to say: for those members who are not encumbering the streets of Los Angeles with their own cars. . . .

the lobby (north entrance). Alternatively one can take a taxi. The fare from downtown Los Angeles to the campus is about $1.50. The tentative plans are to provide a fixed menu at the **cafeteria** for the American Physical Society.

The **banquet** of the American Physical Society will take place at the Roger Young Auditorium at 8:00 P.M. The main entree of the dinner (other than the speech of our distinguished speaker, President DuBridge) will be roast prime ribs of beef for which the restaurant is famous. The price of the dinner will be $3.25 per plate. The dinner will be immediately preceded by a cocktail party, from 7 to 8 o'clock at the same place, provided by the Department of Physics of the University of Southern California. Tickets for the dinner and invitations to the cocktail party will be available at the registration desk and should be obtained well in advance.

The Local Committee has tentatively arranged **tours** for members of the Society and their guests who stay on in Los Angeles for the day after the meetings, December 31. Plans for these tours are not now definite. One will be to Mount Wilson and the other to the Scripps Institute of Oceanography at La Jolla. Details of the visits and the transportation will be arranged during the meeting.

Read the **preliminary announcement of the 1956 February (Houston) Meeting** which follows immediately. Other subsequent meetings and their deadlines are announced on page 7 of this Bulletin, as also the rules for preparation of abstracts (pay heed to the new rule imposing a special and expensive condition on the withdrawal of abstracts that have already gone to press).

Titles and abstracts of papers contributed to this meeting are printed hereinafter, and in exactly this form they will reappear in a future issue of *The Physical Review*. Errata probably will be printed on an adjacent page of that issue if mailed ***immediately on the receipt of this Bulletin*** to Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. The reason we say "immediately" is that it is desired to republish these abstracts in the *Review* before the end of 1955. If, however, this is infeasible, they will be printed in a later issue of the *Review*. Do not send in the abstract marked with corrections! Write out the corrections in the form "instead of . . . read . . . ." Add nothing.

Post-deadline, ten-minute papers of sufficient importance to warrant their inclusion in a special supplementary programme will be considered by the Local Secretary if the abstracts are received not later than Monday, December 19, at the office of the Local Secretary for the Pacific Coast (the address below). If time permits, the mimeographed abstracts, including the titles and the names of the speakers will be prepared and distributed at the registration desk. These papers will be presented at a session to be announced during the meetings.

W. A. NIERENBERG,
Local Secretary for the Pacific Coast
University of California
Berkeley 4, California

Preliminary Announcement of the 1956 February Meeting

The 1956 meeting of the American Physical Society in the Southwest will be held on Friday and Saturday, February 24 and 25, in the Rice Institute, Houston, Texas. Rooms have been set aside for our members in the Rice Hotel and in the Shamrock-Hilton Hotel; reservation should be made early. Deadline is Friday, December 30, and abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York.

(Please keep this page on file!)

MEETINGS AND DEADLINES FOR THE SEASON 1955–1956

Place	*Meeting dates*	*Deadline date*
Los Angeles	December 28–30	past
New York	January 30–February 4	past
Houston	February 24–25	December 30
Pittsburgh	March 15–17	January 13
Washington	April 26–28	February 17
New Haven	June 21–23	April 27
Eugene*	June 21–23	not decided

* Abstracts for the Eugene meeting are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past.

RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line. **By action of our Council, abstracts will not henceforth be withdrawn from our proofs unless the asker sends ten dollars with his request.**

EPITOME OF THE 1955 LOS ANGELES MEETING

(Personal names are those of invited speakers.)

Wednesday Morning

10:00 A. High-Energy Physics. Fowler, Yodh, Powell, Thorndike. Founders Hall 133.

10:30 B. Solid State I. Contributed Papers. Founders Hall 129.

10:30 C. Nuclear Physics. Contributed Papers. Founders Hall 226.

Wednesday Afternoon

2:00 D. Division of Electron Physics. Field, Gomer, Moore, Woodbury. Founders Hall 133.

2:00 E. Theoretical Physics. Saxon, Gell-Mann, Yennie, Henyey, Teller. Founders Hall 129.

Thursday Morning

9:30 F. Shell Structure. Jacobsohn, Inglis. Contributed Papers. Founders Hall 133.

10:30 G. Physical Oceanography. Revelle, Iselin, Ewing. Founders Hall 229.

10:30 H. High-Energy Physics. Contributed Papers. Founders Hall 129.

Thursday Afternoon

1:00 I. π Mesons. Contributed Papers. Founders Hall 129.

1:00 J. General Physics. Contributed Papers. Founders Hall 226.

2:45 K. Symposium on the Anti-Proton. Segrè, Wiegand, Chamberlain, Murray, Serber. Founders Hall 133.

Thursday Evening

8:00 Banquet of the American Physical Society. DuBridge. Roger Young Auditorium.

Friday Morning

9:30 L. Division of Solid-State Physics. Bowen, Fisher, Shockley, Pellam, Feynman. Founders Hall 133.

10:00 M. *K*-Mesons, etc. Contributed Papers. Founders Hall 129.

10:30 N. Cyclotrons and Scattering. Contributed Papers. Founders Hall 226.

Friday Afternoon

1:30 O. Cosmic Rays and *K*-Mesons. Goldhaber, Stork, Good, Davis, Ney. Founders Hall 133.

1:30 P. Solid State II. Contributed Papers. Founders Hall 129.

1:30 Q. Theoretical Physics. Contributed Papers. Founders Hall 226.

PROGRAMME

WEDNESDAY MORNING AT 10:00

133 Founders Hall

(J. R. RICHARDSON, presiding)

Invited Papers on High-Energy Physics

A1. Nuclear Reactions and Element Synthesis in Stars. W. A. FOWLER, *California Institute of Technology.* (30 min.)

A2. Pion Production by the Inelastic Scattering of Electrons in Hydrogen. G. B. YODH, *Stanford University.* (30 min.)

A3. π-p, p-p, and n-p Collisions at Bevatron Energies. W. M. POWELL, *University of California.* (30 min.)

A4. Nucleon-Nucleon Interactions. A. M. THORNDIKE, *Brookhaven National Laboratory.* (30 min.)

WEDNESDAY MORNING AT 10:30

129 Founders Hall

(W. D. HERSHBERGER, presiding)

Solid State I

B1. The Significance of Nuclear Spin Echo Experiments for the Foundation of Statistical Mechanics. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—We have shown the essential identity of the entropy of information theory and statistical[1] or thermodynamical[2] entropy, and characterized reversible processes as those in which information is conserved, irreversible as those in which information is lost.[2] The Wieder- or Umkehreinwand is then valid if information storage (memory) is possible, invalid otherwise. Boltzmann's statistical argument, replacing the kinetic H-theorem proof criticized by Loschmidt and Zermelo, implicitly admits information loss. Spin echo experiments[3] demonstrate that memory permits reversibility, with irreversibility following loss of stored information. More generally, a kind of "phase coherence" (classical or quantal) corresponds to reversibility, incoherence to irreversibility. For spin echoes, phase memory is carried in Larmor precession of the spins; for inhomogeneous magnetic field Brownian motion is the chief memory destroyer, masking others like spin-spin and spin-lattice interactions. With latter negligible and perfectly homogeneous field, or with memory and retracing of complete dynamical trajectories, entropy increase of spin system would be prevented with resulting reversibility.

[1] J. Rothstein, Science **114**, 171 (1951).
[2] J. Rothstein, Phys. Rev. **88**, 135 (1952).
[3] E. L. Hahn, Phys. Rev. **80**, 580 (1950), Phys. Today **6**, 4 (Nov. 1953).

B2. Ferrimagnetic Interaction and Remanence in Cobalt Carbonate. WARREN E. HENRY, *U. S. Naval Research Laboratory.*—Magnetization studies have been carried out for $CoCO_3$ in strong magnetic fields and at low temperatures to investigate the nature of interactions therein. A ballistic, sample motion method[1] has been used to perform the magnetic measurements in magnetic fields up to 60 000 gauss and at temperatures down to 1.3°K. Cobalt carbonate exhibits ferrimagnetic interaction, has a transition temperature at about 10°K and a moment at 60 000 gauss and 1.3°K of about 0.05 Bohr magneton per atom of cobalt. When the remanence is plotted against the temperature, there seems to be a change in the sign of $(\partial^2 M/\partial T^2)$ at about 3°K. An analysis of the interaction is made in terms of departures[2] from the Brillouin function and in terms of theories[3] of Van Vleck, of Néel, of Gorter, and of Yaffet and Kittel. The observation of ferrimagnetism is also interpreted on the basis of predictions that could be made from recent high-temperature susceptibility measurements of Bizette.[4]

[1] W. E. Henry, Phys. Rev. **88**, 559 (1952).
[2] E. Henry Phys. Rev. **94**, 1146 (1954).
[3] J. H. Van Vleck, J. phys. radium **12**, 262 (1951); Revs. Modern Phys. **25**, 220 (1953); L. Néel, Proc. Roy. Soc. (London) **A64**, 869 (1952); C. J. Gorter, Physica **18**, 861 (1952); Y. Yaffet and C. Kittel, Phys. Rev. **87**, 290 (1952).
[4] H. Bizette, Compt. rend. **241**, 546 (1955).

B3. Frequency Doubling in Ferrites. W. P. AYRES, P. H. VARTANIAN, AND J. L. MELCHOR, *Electronic Defense Laboratory of Sylvania Electric Products Inc.**—The torque equation for the motion of the magnetization in a magnetized ferrite yields a component along the direction of the applied dc magnetic field. The time dependent part of this component is of second order in rf quantities and has previously been neglected. With high incident powers an observable double-frequency output is predicted. A high intensity microwave magnetic field and an orthogonal dc magnetic field were applied to a ferrite body. Double frequency magnetic fields were generated in the same direction as the dc magnetizing field. A primary frequency of 3175 mc was used with peak powers up to 200 watts. The peak output power at 6350 mc was found to increase linearly with the square of the peak input power over a range of 50 db. Reasonable agreement was found between theory and experiment.

* This work was performed under a Signal Corps Contract.

B4. Energy Band Calculations in f.c.c. Thorium.* G. W. LEHMAN, *North American Aviation, Inc.*—The lowest energy bands of face-centered cubic thorium have been worked out along the (001), (011), and (111) directions in

the Brillouin zone using a simplified variational approach originally developed by Kohn.[1] Using the Thomas-Fermi model, it was found that the $5f$ and $6d$ bands form the low-lying states corresponding to the observed lattice spacing. From this model, the $7s$ and $7p$ states lie several electron volts above the Fermi level and have been neglected. The trial wave functions used in the variational calculation were taken as linear combinations of Cubic Harmonics and radial wave functions computed for an energy lying between the two- and threefold degenerate d states at the center of the Brillouin zone. (A more general procedure has been used by Jenkins and Pincherle.[2]) This approximation has the general formal character of Slater's LCAO method where all but nearest neighbor interactions are neglected. The 12 x 12 secular determinant, resulting from the variational approximation, factors along symmetry lines according to the group theoretical results of Bouchaert, Smoluchowski, and Wigner. The energy contours are being used to calculate a density of states curve in f.c.c. thorium.

[1] W. Kohn, Phys. Rev. **87**, 472 (1952).
[2] D. P. Jenkins and L. Pincherle, Phil. Mag. **45**, 93 (1954).
[3] This work performed under Contract for the U. S. Atomic Energy Commission.

B5. Quadrupole Broadening of NMR Lines by Reversible Axial Stress. R. G. SHULMAN, B. J. WYLUDA, AND H. J. HROSTOWSKI, *Bell Telephone Laboratories.*—Nuclear electric quadrupole moments interact with electric field gradients at the nucleus. In a perfect cubic crystal $\nabla \cdot \vec{E} = 0$, and there are no quadrupolar interactions. Watkins and Pound[1] have shown that in alkali halides internal strains destroy the spherical symmetry of the electric field. Nuclear magnetic resonance[2] studies of the semiconductors InSb and GaSb have revealed no quadrupolar interactions in our samples indicating a high degree of crystalline perfection. By applying axial stresses to these crystals, we have been able to destroy the crystalline symmetry reversibly, thereby producing quadrupole broadening of the nuclear magnetic resonance lines. In InSb the application of 500 lb/in.[2] along the <110> axis reduced the intensity of the In^{115} resonance by 11% and increased the second moment by 30%. This corresponds to $e^2qQ \sim 45$ kc under these conditions.

[1] G. D. Watkins and R. V. Pound, Phys. Rev. **89** 658 (1953).
[2] Shulman, Mays, and McCall, Phys. Rev. **98**, 1182 (1955).

B6. Quadrupole Polarization of Charge-Clouds in Ions.* T. P. DAS AND R. BERSOHN, *Department of Chemistry, Cornell University.*—A variational method has been developed for calculating the quadrupole polarization of charge clouds of ions. This method obviates the step by step numerical integration of the relevant Schrödinger equation as adopted by Foley, Sternheimer, and Tycko.[1] The form of the variation function for the perturbation of the electronic wave function by an external charge at distance r is taken as

$$u_1 = u_0 r^2 (3\cos^2\theta -) P(r),$$

where $P(r)$ is a polynomial in r containing adjustable parameters. Preliminary calculations for the radial $2p \rightarrow p$ excitations in Na^+ and Al^{+++} give values of γ_∞ of -5.2 and -3.1, respectively. The value -5.2 for Na^+ is reasonably close to Sternheimer's[2] value of -4.56. A brief discussion of the method will be given and the complete values of γ_∞ for Na^+ and Al^{+++} will be reported.

* This work was supported by the U. S. Atomic Energy Commission.
[1] Foley, Sternheimer, and Tycko, Phys. Rev. **93**, 734 (1954).
[2] R. M. Sternheimer (private communication).

B7. Magnetic Resonance Demonstration of Charge Transfer in Iron Group Fluorides. M. TINKHAM,* *Clarendon Laboratory, Oxford.*—The paramagnetic resonance spectra of iron group fluorides highly diluted with ZnF_2 have been studied. In the cases of Mn^{++}, Co^{++}, and Fe^{++}, viewed along principal axes, each line of the normal spectrum is found to be split into 15 "super-hyperfine structure" components by the interaction of the magnetic electrons with the nuclei of the surrounding F ions. The coupling constants are 10–20 gauss, depending on the cation, the neighbor involved, and the angle. The large magnitude of the effect requires that the orbitals of the magnetic electrons be modified by attaching orbitals centered about the F nuclei. It is then deduced that the dominant interaction occurs through attached s-orbitals about the F ions. The anisotropy comes from the direct dipolar interaction with the central magnetic ion and from attached p-orbitals. In terms of admixtures, their seems to be roughly equal amounts of fluorine s, p_σ, and p_π orbitals, the admixtures being of the order of 1% of each type on each center. This picture receives striking support from the *absence* of resolvable structure in the case of Cr^{+++}, which has no magnetic electrons in σ-bonding orbitals and hence can not attach the s-functions needed to give the dominant interaction.

* National Science Foundation Postdoctoral Fellow; now at University of California, Berkeley.

B8. Electron Spin Resonance of Defect Centers in Magnesium Oxide.* JOHN E. WERTZ AND JUANA L. VIVO, *University of Minnesota.*—Attempts to find electron spin resonance (ESR) absorption by imperfection centers in MgO were complicated by the multiplet spectra of impurities. After a detailed study, we found one line which disappears on heating in vacuum. The splitting factor g is 2.003 along a principal axis, and the corresponding line width is 4.2 gauss, twelve-fold narrower than for KCl. This line and an absorption band at 2600 A which disappears on heating in vacuum, are presumably the result of excess oxygen. Heating in air at 600°C increases the intensity of the ESR line. Tentatively it is assumed that the ESR centers are O^- ions, although experiments[1] on oxygen uptake at higher temperatures would indicate that at 600° the process would be very slow. Exposure to x-rays after annealing gives an ESR line of similar g-value and width, which decays slowly.

* Supported in part by the Air Force Office of Scientific Research.
[1] B. V. Haxby (unpublished results).

WEDNESDAY MORNING AT 10:30

226 Founders Hall

(C. C. LAURITSEN, presiding)

Nuclear Physics

C1. Isotope Shift in the Spectra of Hg^{198}–Hg^{200}. FRED MCCLUNG AND JOHN R. HOLMES, *University of Southern California.*—By using separated isotopes, direct measurements of the shift have been made on several lines. A direct recording system using electronic detection, photomultiplier tube or PbS cell, and recording on a strip chart recorder,

is used. High resolution is obtained from a Fabry-Perot interferometer, which is scanned by varying the air pressure between the plates, and is crossed with a grating. The light from each discharge tube is alternately directed into the interferometer while scanning, providing a direct measurement of the shift without overlapping of the lines of the two sources. Because of the type of recording, probable errors are small. Preliminary results are

Wavelength (A)	$\nu^{198}-\nu^{200}$ cm^{-1}
5769.6	−0.0052
5460.7	0.0594±0.0005
4916.0	0.013 ±0.001
4358.3	0.0576±0.0004
4046.5	0.0557

The spacers used were 4.60, 4.59, and 13.50 cm. Other lines are under study.

C2. Obtaining High Temperatures for Nuclear Fusion. R. E. Vollrath and J. A. R. Samson, *University of Southern California.*—The possibility of reaching extremely high temperatures in a limited amount of a gas is being explored. The so-called "pinch effect" first noted by Northrup in 1907 in connection with liquid conductors may make it possible to heat a volumn of gas by means of an electrical discharge and at the same time confine it to a thin column out of contact with any walls. Such a contraction occurs as the result of the interaction of the current in the discharge with its own magnetic field. We have noted the beginning of such a contraction in a toroidal discharge tube containing hydrogen and excited by pulsed discharges. The tube encircles one leg of a closed Hypersil transformer core. The other leg of the core is encircled by a single turn of copper ribbon through which a 150-μf capacitor at 5000 v is discharged. Currents of 5000 amp are obtained through hydrogen at 1-mm pressure and lower. The discharge was initiated with ease at these low pressures by aid of photoelectric emission from a thin film of caesium deposited inside the tube.

C3. A Neutron Dosimeter with Uniform Sensitivity from 0.1 to 3.0 Mev.* J. De Pangher and W. C. Roesch, *General Electric Company.*—The dose rate sensitivity of a moderated BF_3 counter was investigated as a function of moderator thickness and neutron energy. Neutrons were obtained with a 2.0-Mev Van de Graaff accelerator and from a PoB source. The dose rate was calculated by the first-collision theory of neutron dose from flux measurements made with a long counter. For cylindrical moderators with axes perpendicular to the neutron beam and for a given neutron energy, the dose rate sensitivity increased with moderator thickness, reached a maximum, and decreased. These sensitivity curves, for three energies investigated, intersected in the region beyond the maximum at 4.5 in. of paraffin. A cylindrical paraffin moderator 12 in. long and with a 4.5-in. wall was constructed to enclose a brass BF_3 counter 1 in. in diameter with a sensitive region 7 in. long. This dosimeter showed a sensitivity constant to within 10% from 0.1 to 3.0 Mev.

* This paper describes in part, work conducted under Contract between the General Electric Company and the U. S. Atomic Energy Commission.

C4. Nonelastic Cross Sections at 14 Mev.* M. H. MacGregor, William P. Ball, and Rex Booth, *University of California, Livermore.*—The 14-Mev neutron beam from the Livermore Cockcroft-Walton Accelerator was used to measure nonelastic cross sections by means of the sphere transmission technique. Automatic equipment was built which removes and replaces the sphere and records data at four detector biases simultaneously. Table I gives uncorrected cross-section data in barns.

Table I.

Neutron bias (Mev)				
Be	0.79	0.66	0.56	0.44
C	0.77	0.68	0.59	0.47
Mg	1.12	1.01	0.94	0.85
Al	1.12	1.03	0.96	0.88
Fe	1.43	1.38	1.33	1.25
Ni	1.45	1.40	1.36	1.31
Cu	1.59	1.52	1.48	1.41
Sn	1.96	1.92	1.87	1.80
Sb	2.03	1.96	1.89	1.82
Pb	2.65	2.59	2.52	2.45

Approximate corrections for multiple scattering and elastic energy loss will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

C5. Neutron Yields from 32-Mev Protons on Thick Targets.* George P. Millburn, Burton J. Moyer, Yuin-Kwei Tai, and Selig N. Kaplan, *University of California, Berkeley.*—The yield of neutrons from 32-Mev protons bombarding thick targets (greater than a range) have been measured for 59 elements and compounds. The neutrons were detected by capturing them in a $MnSO_4$ solution surrounding the target and counting the resulting Mn^{56} activity with immersion Geiger counters. The detection system was calibrated against a standard Ra-α-Be source. The yields for light elements varied from 18.1×10^{10} for Be to 0.60×10^{10} for C (in neutrons per μcoulomb). The yield increased abruptly by a factor of 2 at two places, near $Z=20$ and $Z=30$. A sharp dip was found at Ni; yields were Co, 7.7×10^{10}; Ni, 3.1×10^{10}; Cu, 8.5×10^{10}. The yield from neighboring odd-even and even-even nuclei for $Z<30$ fluctuated by about 20%. U gave the highest yield measured, 22×10^{10}, but elements near Pb had a lower yield (10×10^{10}) than elements for $Z=46$ to 74 (13×10^{10}). The yields were analyzed in terms of the average number of neutrons emitted per nuclear interaction, averaged over energy from 0 to 32 Mev.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

C6. Double-Channel Magnetic Beta-Ray Spectrometer for Short-Lived Activities.* C. R. Sun and Byron T. Wright, *University of California, Los Angeles.*—A semicircular beta-ray spectrometer has been developed for studying proton-induced activities with half-lives as short as tenths of seconds and end-point energies to 12 Mev. At a given magnetic field, beta particles of different momenta are focused at distances of twelve and eight inches from the source. This double channel arrangement provides a means of normalization which is superior to that of using a monitor counter near the source in those cases in which there are gamma rays from secondary activities. The choice of the detector positions has been optimized. The slit system is adjustable. At the present setting, the resolution for each channel is 1.7% and the transmissions for the 12-in. and 8-in. channels are 0.052% and 0.076%. Targets, after being irradiated in the cyclotron beam, can be transferred to the source position within 0.2 second through a 16-foot pneumatic tube.

* This work was partially supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C7. Preparation of Thin N^{14} Targets.* F. B. Hagedorn, *California Institute of Technology.*—Difficulties in preparing thin nitrogen targets, both stable and sufficiently free from carbon and oxygen contamination, has delayed a detailed investigation of the elastic scattering of protons from nitrogen. At least a partial solution to this problem has been found. A 20-kev mass-28 nitrogen ion beam was collected in

beryllium. The targets thus prepared were bombarded with the proton beam from an electrostatic accelerator. Magnetic analysis of the elastically scattered protons indicates that the nitrogen layer is about 2 kev thick for 1.7-Mev protons and that the ratio of nitrogen to carbon and oxygen is about 5:1. Reducing the carbon and oxygen contamination to the present level has involved using freshly evaporated beryllium as a collector and keeping the collection chamber at a pressure of 10^{-6} mm. Further reduction of this contamination appears extremely difficult. This type of target has not decomposed either under bombardment or from exposure to the atmosphere for as long as a month. Nitrogen ions driven into tantalum have also proven to be exceptionally stable targets. This technique is now being investigated for other nuclei. Preliminary work in preparing 90% enriched N^{15} targets has been successful.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C8. Half-Life of Sn^{110}.* S. W. Mead, M. D. Petroff, and W. O. Doggett, *University of California, Berkeley* (introduced by A. C. Helmholz).—A half-life of 4.0±0.2 hours has been tentatively assigned to Sn^{110}. A target containing enriched Cd^{109} was bombarded with 32-Mev alphas in the 60-inch cyclotron. After separation of indium, sources were prepared from the tin fraction and were observed with a crystal spectrometer and a magnetic lens spectrometer. The 670-kev γ ray in the decay of In^{110} was observed to grow with a half-life of approximately 1 hour followed by a 4-hour decay. A γ ray of 285 kev, identified with the decay of In^{109} by McGinnis,[1] was also followed in the spectrometer. Readings were begun half an hour after chemical separation. Since no growth was observed and the decay half-life was, within experimental error, the same as that of the 670-kev line, it appears that the 285-kev line might be properly identified with an excited state of In^{110} formed in the Sn^{110} decay. Further investigations are in progress in an attempt to clarify this situation.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] C. L. McGinnis, Phys. Rev. **81**, 734 (1951).

C9. Inelastic Scattering of Protons from Li^7, C^{13}, Mg^{24}, and Si^{28}.* Homer E. Conzett, *University of California, Berkeley*.—Thin targets of Li, polystyrene, Mg, and SiO were bombarded with 12-Mev protons, and differential cross sections were measured on proton groups identified with the 4.65-Mev level in Li^7, the 4.43 in C^{12}, the 1.368 in Mg^{24}, and the 1.78 in Si^{28}. The Li distribution shows a maximum near 12° (c.m.), a minimum at 106°, and a secondary maximum at 125°, with approximate relative cross sections of 2.7, 1.0, and 1.1, respectively. The C and Mg data are significantly different from those found at 10 Mev.[1] At 12 Mev, on C a maximum appears near 10°, a minimum at 95°, and a maximum at 160°, with relative cross sections of approximately 6.1, 1.0, and 3.1. The Mg distribution shows a sharp rise forward of 20°, continuing to 8°, the smallest angle at which a measurement was possible. Minima appear at 50° and 115°, maxima at 85° and 140°. The Si distribution has maxima at 20° and 165°, a minimum at 120°. These angular distributions will be compared with those predicted by theory.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] G. E. Fischer, Phys. Rev. **96**, 704 (1954).

C10. Internal Conversion Coefficients of Low Excited States of F^{19}.† W. R. Mills, Jr.,* H. H. Hilton, III, and C. A. Barnes,‡ *California Institute of Technology*.—A magnetic lens spectrometer has been used to measure the internal conversion electron yield of the first and second excited states of F^{19} produced by $F^{19}(pp')F^{19*}$. A NaI(Tl) crystal was used to obtain the γ-ray yields. Correcting for the theoretical K to L ratio, and the anisotropy of the 197-kev state, we obtained $\alpha_K(109)=(2.10\pm0.45)\times10^{-6}$, $\alpha_K(.197)=(1.91\pm0.60)\times10^{-6}$. These compare with the theoretical values as follows:

	α_K(experimental)/α_K (theoretical)			
	E1	*M1*	*E2*	*M2*
109	1.14±0.24	2.89±0.62	0.089±0.019	0.282±0.060
197	6.84±2.1	10.8 ±3.4	0.888±0.28	1.79 ±0.56

Hence the assignment of *E1* to the 109-kev state and *E2* to the 197-kev state is consistent with $J=1/2^-$ for the 109-kev state and $J=5/2^+$ for the 197-kev state.

* Now at General Electric Company, Schenectady, New York.
† Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
‡ Now at University of British Columbia, Vancouver, B. C., Canada.

C11. Elastic Scattering of Protons at 9.9 Mev.* Norton M. Hintz, *University of Minnesota*.—Using 9.89-Mev protons from the first stage of the Minnesota linear accelerator, a program of elastic scattering has been initiated. The proton beam is deflected into a 24-in. diameter scattering chamber with a rotatable lid to support the detector assembly. Either solid or gas targets may be used. A NaI detector (~3% energy resolution) with conventional electronics is used. The angular resolution is approximately ±1.5°. Points were taken at 5° intervals; generally from 15° to 165°. Data will be presented for Be,[1] N, A, Al, Ni,[2] Sn, and Au. The general features of the angular distributions are similar to the data at 22 Mev[3] in that the light element cross sections oscillate above coulomb at the back angles and the heavy elements oscillate below. The cross section for gold is Coulombic out to 170°.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Unpublished data of S. W. Rasmussen.
[2] Uupublished data of M. K. Brussel.
[3] B. L. Cohen and R. V. Neidigh, Phys. Rev. **93**, 282 (1954).

Wednesday Afternoon at 2:00

133 Founders Hall

(J. W. M. DuMond, presiding)

Invited Papers Sponsored by the Division of Electron Physics

D1. Modern Trends in the Interaction of Electron Beams with High-Frequency Fields. L. M. Field, *Hughes Aircraft*. (30 min.)

D2. Some Experiments in Field and Ion Emission. R. Gomer, *University of Chicago*. (30 min.)

D3. The Dissociation of Solid Compounds by Electron Impact. G. E. Moore, *Bell Telephone Laboratories*. (30 min.)

D4. Some Electronic Effects of Germanium Containing Double Acceptor Impurities. H. H. Woodbury, *General Electric Research Laboratory*. (30 min.)

WEDNESDAY AFTERNOON AT 2:00

129 Founders Hall

(R. F. CHRISTY, presiding)

Invited Papers in Theoretical Physics

E1. The Optical Model of the Nucleus. D. S. SAXON, *University of California, Los Angeles.* (25 min.)

E2. Causality and Scattering. M. GELL-MANN, *California Institute of Technology.* (25 min.)

E3. The Interactions of Electrons and Nucleons. D. R. YENNIE, *Stanford University.* (25 min.)

E4. Numerical Calculations of Stellar Evolution. L. G. HENYEY, *Radiation Laboratory, Livermore Site, University of California.* (25 min.)

E5. Velocity Dependence of the Nuclear Potential. E. TELLER, *University of California, Berkeley.* (20 min.)

THURSDAY MORNING AT 9:30

133 Founders Hall

(W. A. FOWLER, presiding)

Shell Structure and Nuclear Physics

Invited Papers

F1. Some Current Problems in Collective Nuclear Models. B. A. JACOBSOHN, *University of Washington.* (30 min.)

F2. Origin of Nuclear Moments of Inertia. D. R. INGLIS, *Argonne National Laboratory.* (30 min.)

Nuclear Structure

F3. Low-Lying Level Structure of the Zn^{65} Nucleus.* J. B. MARION† AND R. A. CHAPMAN, *The Rice Institute.*—Sulfur and beryllium samples have been used as energy-selective neutron absorbers to investigate the low-lying level structure of the Zn^{65} nucleus. The transmission through the samples of the neutrons from the $Cu^{65}(p,n)Zn^{65}$ reaction was measured as a function of the proton energy and the known resonances in the neutron total cross sections of S and Be were observed for both the neutron group leaving Zn^{65} in the ground state and for a group leaving Zn^{65} in an excited state at 118±8 kev. This excited state is probably identical with that from which γ radiation has been observed[1] in the Ga^{65} decay. At a proton energy of 2.9 Mev, the two neutron groups are of approximately the same intensity. The Q-value for the $Cu^{65}(p,n)Zn^{65}$ reaction was found to be -2.131 ± 0.005 Mev. The 585-kev resonance in S was observed with neutrons from the $V^{51}(p,n)Cr^{51}$ reaction and the threshold energy of 1.566 Mev for this reaction was confirmed.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California.
[1] B. Crasemann, Phys. Rev. **93**, 1034 (1954).

F4. Excited States of Ge^{72}.* E. BRUN, W. E. MEYERHOF, AND J. J. KRAUSHAAR, *Stanford University.*—The decay of 14-hour Ga^{72} has been studied[1] and more recently also that of 26-hour As^{72} in order to obtain information on the excited states of Ge^{72}. The 0.3-μsec isomeric state[2] has been found to be the first excited state at 0.69 Mev, with spin zero and even parity. The second and third excited states are at 0.84 and 1.46 Mev and have been assigned spin two and even parity. The gamma rays feeding the isomeric state have been determined by delayed coincidence experiments, and originate primarily at a new level at 2.39 Mev. Decay schemes of both Ga^{72} and As^{72} will be presented. Possible reasons for the exceptional spin of the first excited state of Ge^{72} will be discussed.

* Supported in part by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.
[1] Kraushaar, Brun, and Meyerhof (to be published in Phys. Rev.)
[2] Bowe, Goldhaber, Hill, Meyerhof, and Sala, Phys. Rev. **73**, 1219 (1948).

F5. Differential Cross Sections for the Scattering of Charged Particles by Beryllium.* R. G. SUMMERS-GILL,† *University of California, Berkeley.*—A beryllium target has been bombarded with 12-Mev protons, 24-Mev deuterons, and 48-Mev alpha particles. With the three projectiles the differential cross sections for inelastic scattering leading to the formation of the 2.43-Mev state have been measured. Their magnitude and forward peaking indicate that compound nucleus formation plays a minor role. Application of inelastic scattering theory[1] leads to the assignment 1/2, 3/2, or 5/2 and even parity for this level. A very weak inelastic proton group has been found confirming the recently reported level in Be^9 at ~1.8 Mev. The cross section for the formation of this state is about 1/100 that for the formation of the 2.43-Mev state. The differential cross section for the pickup reaction $Be^9(p,d)Be^8$ has also been measured. This angular distribution agrees favorably with that obtained from the Butler theory of stripping and the known ground states involved.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† National Research Council of Canada Special Scholar.
[1] Huby and Newns, Phil. Mag. **42**, 1442 (1951); Austern, Butler, and McManus, Phys. Rev. **92**, 350 (1953).

F6. Nuclear Spin and Magnetic Moment of 54-min In^{116m}.* L. S. GOODMAN AND S. WEXLER, *Argonne National Laboratory.*—The nuclear spin, magnetic moment, and the sign of the magnetic moment of 54-min In^{116m} have been determined by the atomic beam magnetic resonance method.[1,2] The values found are $I=5\hbar$ and $\mu=4.4$n.m. Multiple quantum transitions[3] were observed in resonances of the inactive In^{115} used for the calibration of the magnetic fields. Some properties of these transitions and the limitation in accuracy of the determination of the nuclear magnetic moment of In^{116m} introduced by their presence will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. R. Zacharias, Phys. Rev. **61**, 270 (1942).
[2] L. Goodman and S. Wexler, Phys. Rev. **99**, 192 (1955).
[3] P. Kusch, Phys. Rev. **93**, 1022 (1954).

F7. 15-Mev Gamma Radiation from $B^{11}+d$.† C. A. BARNES* AND R. W. KAVANAGH, *California Institute of Technology.*—Several investigators have reported observation of 15.1-Mev γ radiation in C^{13} via $Be^9(\alpha,n)$, $B^{10}(He^3,p)$, $B^{11}(d,n)$, $C^{12}(p,p')$, and $C^{12}(n,n')$. Using a 4 in. x 4 in. NaI(Tl) crystal, we have measured the cross section for the reaction $B^{11}(d,n)C^{13*}(\gamma)C^{13}$ from threshold at $E_d=1.633$ ±0.003 Mev to 3.26 Mev. The thin target yield curve exhibits a sharp decrease in slope at $E_d=2.18\pm0.01$ Mev, thereafter remaining fairly constant except for a weak resonance ($\gamma\sim175$ kev) at 3.07 Mev. The cross section at $E_d=2.18$ Mev is 17 ± 5 mb. Using magnetic analysis at 60°, attempts to detect α particles from C^{13*} to Be^8 and Be^{8*} gave negative results; assuming isotropy, we estimate $\Gamma_\alpha/\Gamma_\gamma<5$. The 15.1-Mev state in C^{13} presumably being the analog of the B^{13} ground state, the branching of the B^{13} β decay was examined. γ rays of 4.4 Mev were found in coincidence with $1.3\pm0.4\%$ of the β transitions, indicating $J=1^+$ for B^{13}. β coincidences with 3.2-Mev γ rays were not present for more than 0.2% of total decays, nor for more than 0.2% with 7.6-Mev γ rays.

* Present address: University of British Columbia, Vancouver, B. C., Canada.
† Assisted by the Office of Naval Research and the U. S. Atomic Energy Commission.

F8. Nuclear Compressibility and the O^+ States of Oxygen-Sixteen and Carbon-Twelve.* R. A. FERRELL AND W. M. VISSCHER, *University of Maryland.*—The anomalously large β-decay ft-value of C^{14} can be accounted for by an accidental cancellation in the matrix element.[1] O^{14} is a member of the same isotopic spin triplet as C^{14} and its β-decay ft-value should be the same, except for Coulomb effects. Actually, the O^{14} ft-value is fifty times smaller,[2] which can be naturally accounted for by a 6% greater size due to the repulsive effect of the two additional protons. This changes the ground-state wave function so that the cancellation is no longer nearly complete. Employing harmonic oscillator wave functions, we have evaluated the Coulomb force producing the size increase and thus have determined the nuclear compressibility. A straightforward calculation of the radial modes of oscillation of the O^{16} and C^{12} nuclei then yields O^+ excited levels at 6.97 Mev and 8.20 Mev, as compared experimentally with 6.06 Mev and 7.65 Mev, respectively. Considering the limitations of the model, the agreement is satisfactory.

* Research supported by the Office of Naval Research.
[1] B. Jancovici and I. Talmi, Phys. Rev. **95**, 289 (1954), and a paper by the present authors (submitted to *The Physical Review*).
[2] J. B. Gerhart, Phys. Rev. **95**, 288 (1954).

F9. An Anomaly in Nuclear Energy Level Density Measurements.* G. IGO AND H. E. WEGNER, *Brookhaven National Laboratory.*—An analysis has been made of nuclear reactions which proceed through a compound nucleus mechanism and in which the nuclei are excited into the continuum. In the interpretation of these reactions, which determine the dependence of the level density on excitation energy and upon atomic number, one uses the level density of a degenerate Fermi gas, const $\exp[2(aE)^{\frac{1}{2}}]$, where E is the energy of excitation. When inelastic scattering and reaction experiments are corrected for contributions from noncompound nucleus processes, the quantity a determined from the corrected spectrum increases monotonically with atomic number. This is in agreement with the predictions of the Fermi gas model[1] and is compatible with the dependence on atomic weight of the neutron spectroscopy level density measurements at approximately 8 Mev. On the other hand, the value of a determined from excitation function experiments and from (α,p) reactions at 40 Mev, corrected for noncompound nucleus processes, shows an anomalous behavior. The quantity a is constant, independent of atomic number, and an order of magnitude smaller than in the former group.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Lang and LeCouteur, Proc. Phys. Soc. (London) **A67**, 586 (1954).

THURSDAY MORNING AT 10:30

229 Founders Hall

(C. H. ECKART, presiding)

Invited Papers on Physical Oceanography

G1. Heat Flow through the Ocean Bottom. R. REVELLE, *Scripps Institution of Oceanography.* (30 min.)

G2. General Circulation of the Ocean. C. O'D. ISELIN, *Woods Hole Oceanographical Institution.* (30 min.)

G3. Earthquake Waves as a Tool for Exploring Ocean Basins. M. EWING, *Lamont Geological Observatory, Columbia University.* (30 min.)

THURSDAY MORNING AT 10:30

129 Founders Hall

(E. W. COWAN, presiding)

High-Energy Physics

H1. Analysis of Nuclear Emulsion Tracks by Scattering Measurements. JOHN S. URBAN AND JOHN J. MCCLURE, *University of Oklahoma.*—A technique will be described for analyzing tracks in nuclear emulsions which makes use of only an arbitrary section of track. Such a technique is particularly useful when the particle has left the emulsion or decayed in its flight. From scattering measurements only, the mass of a particle and its residual range may be found. The equation for the second difference due to scattering as a function of residual range is well known. A graphical method of obtaining approximate values of two constants which appear in the equation leads to an evaluation of these constants by method of successive approximations involving least squares. One of these constants yields the mass of the particle and the other its residual range.

H2. High-Velocity Particle Ranges in Emulsion.* WALTER H. BARKAS, PAUL H. BARRETT, PIERRE CUER, HARRY H. HECKMAN, FRANCES M. SMITH, AND HAROLD K. TICHO, *University of California, Berkeley.*—The range-velocity relations for all stopping materials are at present considered unreliable at high particle velocities because of recent evidence[1] that the mean ionization potentials are seriously in error. The situation is particularly intolerable for nuclear track emulsion, because important questions regarding the masses and decay schemes of K particles and hyperons depend on accurate energy determinations from the measured ranges of secondaries. A complication in emulsion is that for this material the density must be determined before the matcrial is specified adequately. We have exposed emulsion blocks of accurately measured density to pions and protons for which the momentum is known to about 1 part in 1000. The momentum is measured by 180-degree bending in a magnetic field. Several points on the range curve at equivalent proton energies of up to 800 Mev have been measured to a precision of better than one percent. More ranges are being measured in an effort to reduce the statistical error.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] D. O. Caldwell, Nuovo cimento **8**, 183 (1955); L. Vigneron, J. phys. radium **14**, 145 (1953).

H3. A Strange Cosmic-Ray Event. C. H. SKEEN AND W. Z. OSBORNE, *University of Oklahoma.*—A strange event has been found in a small stack of Ilford G-5, 400 micron pellicles that was exposed to the cosmic radiation at 93 000 ft.* This event consists of a track which emanates from a star and subsequently "splits" into two tracks. Measurements reveal that the three tracks are coplanar in the neighborhood of their intersection. Mass and energy estimates have been made for the various particles involved. Various interpretations of the event consistent with the above measurements are considered, the most plausible of which seems to be that a doubly charged, heavy, unstable particle or fragment was emitted from the star and then decayed in flight into two singly charged particles. Further measurements are now being made.

* Exposed at San Angelo, Texas (41° N geomagnetic latitude) on January 15, 1955 by courtesy of the Office of Naval Research Project "Skyhook."

H4. Cloud-Chamber Observations of μ-Meson Induced Electron Showers.* C. A. ROUSE, *California Institute of Technology.*—During 1476 hours of operation of a magnet-cloud chamber with proportional counter control, 31 pictures were obtained in which electron showers of 40 or more particles were produced in a 5 cm lead absorber by cosmic-ray μ mesons at Pasadena. Of the 31 events, 7 had 100 or more electrons. The cross section per lead nucleus for the production of showers of 40 or more electrons emerging from 5 cm of lead is 3.8×10^{-28} cm^2 and for showers of more than 100 electrons is 2.6×10^{-29} cm^2. These values are in agreement with theoretical cross sections obtained by numerical integration of the knock-on and bremsstrahlung cross sections[1] for μ mesons of spin 1/2 together with the use of cascade shower curves.[2] These cross sections were obtained from direct observations of the showers and have the advantage over previous ionization chamber measurements that no effects of stars and air showers are included.

* Assisted by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission. Reproduction in whole or in part is permitted for any purpose of the United States Government.
[1] R. F. Christy and S. Kusaka, Phys. Rev. **59**, 405, 414 (1941).
[2] B. Rossi and K. Greisen, Revs. Modern Phys. **13**, 240 (1941).

H5. Elastic Scattering of Electrons by Li^6 and Li^7.* J. F. STREIB,† *Stanford University.*—Using techniques developed in this laboratory,[1] the elastic scattering of electrons by Li^6 and Li^7 has been studied,[2] with emphasis on the comparison of their cross sections. With high resolution, the inelastic scattering by the 0.477-Mev state of Li^7 appears as a broadening of the main scattering peak, and its small contribution ($\sim$10%) is determined by comparison with the Li^6 peak. At 187 Mev, $\sigma_7/\sigma_6=\rho$ varies smoothly from 1.00 (35°) to 1.17 (80°). The magnetic contribution to ρ is estimated from the values ρ(187 Mev, 65°)=1.07 and ρ(117 Mev, 118°) =1.12; the two conditions involve equal momentum transfers; a crude interpretation of Rosenbluth's formula[3] indicates that the effect adds 2% at 80° and less at smaller angles. For both isotopes the angular distribution at 187 Mev indicates a charge distribution between the uniform and the Gaussian, with a rms radius $(2.38\pm0.05)\times10^{-13}$ cm, the ratio of rms radii being $r_7/r_6=0.99\pm0.01$.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission, and by the U. S. Air Force through the Office of Scientific Research.
† On leave of absence from the University of Washington. Appointment supported by the National Science Foundation.
[1] Hofstadter, Fechter, and McIntyre, Phys. Rev. **91**, 422 (1953); Phys. Rev. **92**, 978 (1953); Hofstadter, Hahn, Knudsen, and McIntyre, Phys. Rev. **95**, 512 (1954); J. H. Fregeau and R. Hofstadter, Phys. Rev. **99**, 1503 (1955).
[2] Li^6 target courtesy of Oak Ridge National Laboratory.
[3] M. N. Rosenbluth, Phys. Rev. **79**, 615 (1950).

H6. Inelastic Electron Scattering by Carbon.* D. G. RAVENHALL, *Stanford University.*—The experimental results of Fregeau and Hofstadter on the scattering of 187-Mev electrons by Carbon[1] contain differential cross sections for both elastic and inelastic processes. The former can be related to the charge distribution of the nucleus in its ground state, and the latter are associated with nuclear excitation, in this case to each of the first three levels, at 4.43, 7.68, and 9.61 Mev. The spins and parities of the first two levels are known to be 2^+ and 0^+ respectively, and the experimental

results relating to these levels and to the ground state are in qualitative agreement with the predictions of the shell model. In this paper a discussion will be given of the excitation to the 9.61-Mev level, and of the information it gives concerning the spin and parity of this level. Further experiments which could assist in giving an unambiguous assignment will also be discussed.

* Supported by the Air Force through the Office of Scientific Research.
[1] J. H. Fregeau and R. Hofstadter, Phys. Rev. **99**, 1503 (1955).

H7. Z-Dependence of Bremsstrahlung in the Case of Complete Screening.* K. L. Brown, *Stanford University.*—The relative yield of bremsstrahlung produced by Cu, Ta, and U for incident electrons of energy 500 Mev is being measured using the reaction $\gamma+p\rightarrow\pi^{+}+n$ as the photon detector. The π^{+} mesons are detected by observing the positrons from the $\pi\rightarrow\mu\rightarrow e$ decay as used by Crowe and others in previous experiments.[1] The π^{+} mesons are selected in both energy and angle. Therefore, from the kinematics of the reaction, only photons in the energy range 235±12 Mev are detected. The tentative results to date are consistent with a deviation from the Bethe-Heitler bremsstrahlung theory of $-(2.0\pm0.6)\times10^{-6}\ Z^{2}$ percent. This result is in good qualitative agreement with the previously observed experimental deviations from the Bethe-Heitler pair-production theory at high energies.[2]

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Crowe, Friedman, and Motz (in preparation).
[2] For a summary of these results, see Davies, Bethe, and Maximon, Phys. Rev. **93**, 788 (1954).

Thursday Afternoon at 1:00

129 Founders Hall

(R. L. Walker, presiding)

π Mesons

I1. π^{+} Photomeson Production from Various Nuclei at 135°.* William Imhof, V. Perez-Mendez, and H. Easterday,† *University of California, Berkeley, and Livermore.*—Cross sections for the photoproduction of positive pions by the 335-Mev bremsstrahlung of the Berkeley synchrotron from various elements were measured at an angle of 135° to the beam. The elements bombarded were polyethylene, lithium, beryllium, boron, carbon, aluminum, copper, silver, and lead. The pions were identified in a telescope consisting of four plastic scintillators by the π-μ decay method.[1] The relative π^{+} yields for these elements were measured at five different pion energies, ranging from 21 Mev to 65 Mev. At 65 Mev the relative yield per proton in the target nucleus showed an approximate $A^{-1/3}$ dependence agreeing within statistics with the work of Littauer and Walker.[2] Little variation in the relative cross sections at different pion energies was seen except for a drop-off in the relative yield from the high-Z elements at the lower energies (probably resulting from effects of the nuclear Coulomb potential).

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Now at the University of Oregon.
[1] Jakobson, Schuls, and Steinberger, Phys. Rev. **81**, 894 (1951).
[2] Littauer and Walker, Phys. Rev. **86**, 838 (1952).

I2. Neutral Pion Production in Proton-Proton Collisions.* Robert K. Squire and Burton J. Moyer, *University of California, Berkeley.*—The characteristics of the production of neutral mesons in proton-proton collisions near threshold has been studied. The external beam of the Berkeley synchrocyclotron was allowed to bombard a liquid-hydrogen target and the high-energy gamma rays arising from the creation and decay of π^{0} mesons were detected with a counter telescope. Four independent experiments, consisting of three bombarding energies at one angle, and one energy at two angles, allowed a separation of the production contributions from the various angular-momentum states that can occur. The excitation function is composed of two terms: σ (millibarns)$=(0.02\pm0.01)\eta_0^{3}+(0.57\pm0.11)\eta_0^{6}$, where η_0 is the maximum meson momentum in units of μc. The angular distribution is

$$\frac{d\sigma}{d\Omega}=\frac{1}{4\pi}(0.02\pm0.01)\eta_0^{3}+\frac{3}{4\pi}(0.57\pm0.11)\eta_0^{6}\cos^{2}\theta.$$

It appears from this work that the production of π^{0} mesons occurs principally in the P-state, accompanied by two nucleons in a P-state relative to each other, down to energies about 15 Mev above threshold, at which energy this production equals the production in S-states.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

I3. High-Energy Pion-Proton Cross Sections.* Baxter H. Armstrong, *University of California, Berkeley.*—The pion-proton cross sections have been analyzed phenomenologically into a superposition of hard-sphere elastic scattering, and resonance reaction and scattering contributions. The analysis was made in terms of the isotopic spin 1/2 and 3/2 cross sections, a fit to current experimental data being obtained for the $\pi^{+}p$ (or $T=3/2$) case to about 1900 Mev, and for the $\pi^{-}p$ case of 1100 Mev. The superposition obtained was, for the $T=1/2$ cross section, the sum of elastic hard-sphere scattering in the $j=3/2$, $L=2$ state and a pure elastic resonance (reduced width 5 Mev) interfering with elastic hard-sphere scattering in the $j=5/2$, $L=2$ state. The $T=3/2$ cross section was the sum of the well-known $j=3/2$, $L=1$ resonance, hard-sphere scattering in the $j=5/2$, $L=3$ state, and a pure resonance (no hard-sphere scattering) with both reaction and elastic contributions in the $j=7/2$, $L=3$ state. The positions of these resonances were 1180 Mev (incident pion lab energy) for the $T=1/2$ and 1200 Mev for the $T=3/2$ state. The total reduced width in the latter case was 7 Mev. The same hard-sphere radius of 1.22×10^{-13}cm was used throughout.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

I4. Yield of π^{0} Photomesons as a Function of Atomic Number.* J. D. Anderson, R. W. Kenney, and C. A.

McDONALD, *University of California, Berkeley.*—With a single gamma counter[1] at 135° to the incident photon beam, the relative yields of π^0 mesons per nucleon were observed for Be, C, Al, Ti, Fe, Cu, Ag, and Pb. The yields were observed as a function of the maximum energy of the bremsstrahlung beam from the 340-Mev Berkeley Synchrotron. The beam was monitored with a Cornell-type thick-walled ionization chamber. The root-mean-square counting errors at 340 Mev were less than 3% on all targets. The targets were designed to have the same absorption for 100-Mev gamma rays. The full energy curve is within the counting statistics of Panofsky's[2] data normalized to carbon. For $A \gtrsim 27$ the yield per nucleon goes as $A^{-1/3}$. For $A \lesssim 27$ the production was approximately constant and is not within statistics of an $A^{-1/3}$ dependence. The data at other energies (E_{max}=270, 200, and 170 Mev) are within statistics (~20%) of the 340-Mev data and are compatible with a mean free path for reabsorption of 1 to 3 r_0.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Cocconi and Silverman, Phys. Rev. **88**, 1230 (1952).
[2] Steinberger, Panofsky, and Stellar, Phys. Rev. **86**, 180 (1952).

I5. Inelastic Cross Sections for 5-Bev π^- Bevatron Beam in Lead and Aluminum.* JOHN ISE, JR., ANDRE LAGARRIGUE (*Ecole Polytechnique, Paris*), AND ROBERT V. PYLE, *University of California, Berkeley.*—A multiplate expansion cloud chamber, 20 by 16 by 5 inches has been used to obtain the inelastic or absorption cross section for the high-energy π^- beam from the bevatron, in lead and aluminum. Neglecting scattering angles less than 1° the cross sections for lead and aluminum are 1.71±0.13 and 0.40±0.04 barn, respectively. Comparison of these results with cosmic-ray and other measurements will be made.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

I6. Pi Meson Production in Lead and Carbon.* M. ABRAHAM AND S. J. GOLDSACK, *University of California, Berkeley* (introduced by R. B. Brode).—Nuclear emulsion pellicles were flown at about 93 000 feet for eight hours.† Semicircular bands of lead and carbon of approximately equal mass were arranged so that π mesons coming from the right were identified as originating in the carbon, while π's from the left originated in the lead. Assuming that the production of π's is proportional to the geometrical cross sections and that the multiplicity is the same, the ratio of π's from the carbon to π's from lead was calculated to be 2.6. Of the 46 stopping π's observed in the scanning now in progress, the directions of 25 are from the carbon and 21 from the lead. This data indicates that the assumption of equal multiplicity of production in lead and carbon is not valid.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† We are indebted to the Office of Naval Research "Operation Skyhook" for their assistance.

I7. Photoproduction of Neutral Pions from Protons at Forward Pion Angles.* W. S. McDONALD AND VINCENT PETERSON, *California Institute of Technology*, AND DALE R. CORSON, *Cornell University.*—Low-energy recoil protons from the process $\gamma+p \rightarrow p+\pi^0$, detected by nuclear emulsions placed within the hydrogen gas target container, have been used to measure the differential cross section. The entering angle and range of protons stopping in a tilted *C*-2 600-micron emulsion are measured, and from these data the incident photon energy and pion angle can be determined. In this manner protons of energies as low as 5 Mev can be detected at laboratory angles corresponding to emission of a pion at center-of-mass angles as low as 26°. This experiment thus supplements that of Walker and Oakley which covers the same range of photon energies (200-500 Mev), but is restricted to pion angles greater than about 70° resulting from higher minimum detectable proton energy. Common experimental points provide intercomparison of absolute values. The data at lower photon energies may also be compared to the results of the M.I.T. and Illinois groups. The effect of the present results upon the angular distributions and total cross sections deduced from previous data will be presented and discussed. In particular, the measurement in the forward hemisphere provides a sensitive check on the value of B in the angular distribution $A+B\cos\theta+C\cos^2\theta$.

* Research supported by the U. S. Atomic Energy Commission.

I8. Pion Pair Photoproduction.* R. M. FRIEDMAN AND K. M. CROWE, *Stanford University.*—A π^- signal has been observed by bombarding liquid hydrogen with the bremsstrahlung spectrum from 575-Mev electrons with a 2:1 signal:noise ratio. The π^-/π^+ ratio of H relative to C was measured at a 60° laboratory angle for various pion energies by delayed coincidences described elsewhere.[1] Using π^+ photoproduction data,[2] the π^- differential cross section was (in units of millimicrobarn/sterad/Mev/equivalent quantum): 4.6±0.9, 4.4±0.8, 3.2±0.5, 2.1±0.4 at pion energies of 20±10, 34±10, 50±10, and 68±10 Mev, respectively. In addition to statistics, the errors quoted include uncertainties in the C ratio, π^+ cross section, and increase in π^+ yield due to pairs. Uncertainties in energy and subtracted background could alter the absolute cross section by an additional 20%. Checks made at 68±10 Mev pion energy are: (1) signal with meson-deflecting magnet off was ≤16% of the π^- signal; (2) cross sections measured at 400, 495, and 575-Mev primary electron beam energies were 0.3±0.3, 0.3±0.3, and 2.1±0.4, respectively, in the above units.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Crowe, Friedman, and Motz, Bull. Am. Phys. Soc. **29**, No. 8, L3 (1954).
[2] Walker, Teasdale, Peterson, and Vette, Phys. Rev. **99**, 210 (1955).

I9. π^+ Photoproduction Ratio of Deuterium to Hydrogen.* K. M. CROWE, R. M. FRIEDMAN, AND D. C. HAGERMAN,† *Stanford University.*—The ratio of the π^+ photoproduction cross section for D to H has been measured at five laboratory angles for (60±10) Mev pions. C, CH_2, and CD_2 targets were irradiated with the bremsstrahlung spectrum produced by 350-Mev electrons from the Stanford linear accelerator. The counting arrangement has been described elsewhere.[1] The measured ratios are 0.92±0.04, 0.88±0.05, 0.86±0.07, 0.85±0.04, and 0.89±0.07 at laboratory angles of 30°, 45°, 60°, 75°, and 90°, respectively. On the basis of calculations[2] of meson production from deuterons using an impulse approximation and splitting the interaction Hamiltonian into spin-flip and non-spin-flip terms, the results would indicate a predominantly spin-flip interaction. Attempts are being made to compare the results to the phenomenological theory of π^+ photoproduction of Gell-Mann and Watson.[3]

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the Los Alamos Scientific Laboratory.
[1] Crowe, Friedman, and Motz, Bull. Am. Phys. Soc. **29**, No. 8, Abstract L3 (1954).
[2] G. F. Chew and H. W. Lewis, Phys. Rev. **84**, 779 (1951); M. Lax and H. Feshbach, Phys. Rev. **88**, 509 (1952).
[3] M. Gell-Mann and K. M. Watson, Ann. Revs. Nuclear Sci. **4**, 219 (1954).

THURSDAY AFTERNOON AT 1:00

226 Founders Hall

(A. BAÑOS, presiding)

General Physics

J1. Townsend's First Ionization Coefficient in Nitrogen.* MELVIN A. HARRISON, *Seattle Pacific College.*—Measurements of Townsend's first ionization coefficient have been made in nitrogen for values of E/p from 24 to 82. Sodium azide was used as a nitrogen source in an effort to obtain pure nitrogen. Data were also taken in tank nitrogen and mass spectrographic analysis of gas from both sources was made. No impurities were detectable in the sodium azide produced gas, while the tank nitrogen was found to contain some contamination even after a purification process. Results at low values of E/p differ considerably from previously reported data,[1] while at high values the results agree very well with data obtained by Bowls.[2] Values of α/p in tank nitrogen were found to be considerably lower at low E/p than those found in gas produced from sodium azide, although at high values the difference was small. The effect of wall potential on α/p was investigated and was found to be unimportant over a range from 50% to 100% of anode potential.

* Supported by a grant from the Research Corporation.
[1] For references see L. B. Loeb, *Basic Processes of Gaseous Electronics* (University of California Press, Berkeley).

J2. Absorption of Vacuum Ultraviolet Radiation by Thin Plastic Films. G. L. WEISSLER AND L. Z. MAUDLIN, *University of Southern California.*—The absorption coefficients of thin Formvar and collodion films have been determined photometrically between 600 A and 1600 A. Both materials exhibited continuous absorption which rose to a flat maximum at about 1050 A and then decreased towards shorter wavelengths. Collodion showed about twice the value of the absorption coefficient, k, at this maximum than Formvar, with $k_C=6.4\times10^{-6}$ cm^{-1} and $k_F=3.9\times10^{-6}$ cm^{-1} respectively. In nylon and polystyrene, qualitatively only, the absorption was still greater.

J3. Temperature Anomalies in the Properties of Liquid Water. W. DROST-HANSEN AND H. W. NEILL, *New Mexico Institute of Mining and Technology.*—The temperature dependence of a number of properties of aqueous solutions and pure water has been studied using data from the literature. Solubilities of approximately 200 substances have been plotted as a function of temperature. Avoiding unnecessary smoothing it has been found that more or less abrupt changes in solubility occur at one or more of the following temperatures: 15°, 30°, 45°, and 60°C, all within a few degrees. A number of properties of dilute and concentrated aqueous solutions (activity coefficients, transference numbers, ionization constants, and reaction rates) seem to possess similar anomalies, and pure water appears also to exhibit these characteristics (index of refraction, viscosity, vapor pressure, specific heat, ultrasonic absorption). The existence of these anomalies reveal an intrinsic property of liquid water, and a discussion of this will be given in the light of Eucken's polymer model for water and Bjerrum's dipole-dipole structures. The relation between the "two states" model, suggested by Hall to explain the ultrasonic absorption in liquid water, and the ideas presented above will be discussed.

J4. Dependence of the Discrete Acoustic Frequencies Emitted by a Jet on Vortex-Ring Coalescence at Reynolds Numbers up to 7000. A. B. C. ANDERSON (introduced by G. J. Plain).—Visualization of the vortex flow pattern in typical jets emitting jet-tones was made by means of shadowgraph techniques to show the nature of the ever-present process of vortex coalescence in the jet and how this determines the values of the eigentone sound frequencies radiated by the jet. These frequencies are superimposed on the noise background radiated by the jet. The dependence of (a) vortex shedding frequency from the orifice, (b) jet-tone frequencies, and (c) translational velocity of the vortices on Reynolds (Re) number is shown. These studies were carried out with carbon dioxide jets discharging into the atmosphere. The flow channel geometry consisted of an orific plate containing a sharp-edged, circular orifice, 0.250 in. in diameter and 0.093 in. thick attached to a large stilling tank partly filled with sound-absorbing material to eliminate any effects of cavity resonances on the jet. The studies were carried out over the range from Re zero to Re 7000 where $\mathrm{Re}=v\rho t/\mu$ where v is mean velocity of discharge of jet; ρ, gas density; t, orifice plate thickness, and μ, gas viscosity.

J5. Projectile Penetration into Sand. EARLE B. MAYFIELD, HARVEY L. MORRISON, AND WILLIAM A. ALLEN, *U. S. Naval Ordnance Test Station.*—When a projectile penetrates with velocity v into granular material such as sand, its negative acceleration is predicted by Poncelet's[1] equation, $-dv/dt=\alpha v^2+\beta$, where the parameters α and β are constants. Prior theoretical[2] effort has been based solely upon knowledge of experimental determination of maximum depth of penetration. A new approach has been made in which projectile arrival times have been measured at several spatial stations in sand. When the projectile breaks a fine grid wire embedded in the medium, the bias is removed from a thyratron and a condenser discharges through a neon bulb to produce a light pulse which is photographed with a sweeping-film camera. Several rounds of a cylindrical steel 0.50-cal projectile 1½-in. in length have been fired from a rifled barrel at about 2800 ft/sec into quartz sand of 1-mm grain size and specific gravity 1.64. Poncelet's equation with the value $\alpha=0.0564\pm0.0015$ represents, within experimental uncertainty, the dynamical behavior of the projectile during the first 40 cm of penetration. Penetration subsequent to this depth is anomalous.

[1] J. V. Poncelet, Mém. acad. sci. **18**, 55 (1829).
[2] Marguerite M. Rogers, Phys. Rev. **99**, 1632 (1955).

J6. Phase Transformations in the Microstructure of Explosively Loaded Iron and Steel. E. W. LAROCCA (introduced by G. J. Plain).—By subjecting annealed low carbon steel and commercially pure iron to explosive loadings, structures resembling martensite are induced in the materials. The structure, which is of a Widmanstatten form, is most noticeable in Armco iron. X-ray diffraction studies show no residual phases other than alpha iron present after impulsive loading, but the microstructure indicates a phase change has occurred (locally) with alpha iron reforming along the octahedral planes of the gamma phase.

J7. Deformation Zones Produced by Explosive Shocks in Ferrous Metals. SAMUEL KATZ, *Stanford Research In-*

stitute.—Collision of explosive-induced shocks in ferrous metals produces characteristic deformation zones. In low and medium carbon steels these zones are narrow regions of intense twinning, with sharp boundaries outside of which less than 10% of the grains are twinned, and with a narrow central strip (0.1 mm) of decreased twin density. These observations suggest the existence of a minimum stress and impulse required for this twinning transformation. For collision at normal incidence a preferred twin orientation parallel to the collision plane is observed. Twin-free regions symmetrically oriented with respect to the collision zone may be explained by an untwinning mechanism. The shock velocity of 5 mm/μsec determined from these experiments[1] is independent of the heat treatment and carbon content (0.01–0.4% C), and suggests that these collision zones are associated with the phase transformation in iron at 131 kb reported by Minshall.[2] This and the observed dependence of collision zone width on explosive and specimen thickness lead to attenuation estimates. Comparable loading of stainless steel specimens (Types 304 and 310) transforms the collision region to martensite, as indicated by a marked increase in permeability.

[1] S. Katz, Phys. Rev. **98**, 256(A) (1955).
[2] S. Minshall, Phys. Rev. **98**, 271(A) (1955).

J8. Free Surface Motion Due to Obliquely Incident Shock Waves. J. O. Erkman, *Stanford Research Institute.*—The problem is considered of a uniform shock obliquely incident on the free surface of a solid or a liquid for which an isentropic equation of state is known. As the shock progresses along the surface, the pressure is relieved by a rarefaction fan which is centered at the intersection of the shock and the surface. The velocity and direction of the resulting flow may be calculated on the basis of the hydrodynamic theory as a function of the angle of incidence of the shock and the shock strength. Results of such calculations for iron, aluminum, and water will be presented. Failure of this simple flow pattern occurs when the velocity behind the incident shock becomes sonic. If the angle of incidence and the flow can be observed by using high speed photography techniques, the calculations may be compared directly with experiments. Such observations for water are discussed.

J9. Normal Modes Characterizing Magneto-Elastic Plane Waves. Alfredo Baños, Jr., *University of California, Los Angeles.*—In an earlier paper we presented the general theory of Alfvén waves in an ideal, unbounded, homogeneous and isotropic, conducting fluid embedded in a constant and uniform field of magnetic induction. The techniques employed there have now been extended to the study of homogeneous magneto-elastic plane waves in an unbounded conducting solid, which is fully characterized by its Lame moduli and by the rigorously constant macroscopic parameters μ, ϵ, and σ. It is found that, in the presence of the magnetic field, the medium sustains five distinct modes of propagation as already pointed out by Knopoff. The first two are *pure shear* waves, one of which is a slightly attenuated shear mode with phase velocity modified anisotropically by the presence of Alfvén's phase velocity, and the other is a highly attenuated modified electromagnetic wave (modified by the presence of the phase velocity of shear waves). The remaining three are *shear-compression* waves, except in certain preferred directions which are discussed. The three modes in question can be characterized by saying that one mode exhibits a phase velocity intermediate between the phase velocities of shear waves and compressional waves, the second mode has a phase velocity which exceeds that of compressional waves, and the last mode is again a modified electromagnetic wave.

Thursday Afternoon at 2:45

133 Founders Hall

(E. M. McMillan, presiding)

Invited Papers on the Anti-Proton

K1. Properties of the Anti-Proton. E. Segrè, *University of California, Berkeley.* (20 min.)
K2. Mass Determination of the Anti-Proton. C. Wiegand, *Radiation Laboratory, University of California.* (30 min.)
K3. The Velocity-Selecting Čerenkov Counter. O. Chamberlain, *University of California, Berkeley.* (20 min.)
K4. Observations on Negative Particles of Protonic-Mass Stopping in a Čerenkov Counter. J. J. Murray, *Radiation Laboratory, University of California.* (10 min.)
K5. Theoretical Background of the Anti-Proton. R. Serber, *Columbia University.* (30 min.)

Thursday Evening at 8:00

Roger Young Auditorium

(R. T. Birge, presiding)

Banquet of the American Physical Society

Address of Welcome: F. D. Fagg, Jr.
After-Dinner Speech: L. A. DuBridge, "Physicists Wanted"

FRIDAY MORNING AT 9:30

133 Founders Hall

(S. SIEGEL, presiding)

Invited Papers Sponsored by the Division of Solid-State Physics

L1. Electronic Structure of the Heaviest Metals. D. B. BOWEN, *North American Aviation.* (30 min.)

L2. Developments in Crystal Growth (with movies). J. C. FISHER, *General Electric Research Laboratory.* (30 min.)

L3. Recent Developments in Transistor Physics. W. SHOCKLEY, *Beckman Instruments, Inc.* (30 min.)

L4. Normal Fluid Excitation in Liquid He ii. J. R. PELLAM, *California Institute of Technology.* (30 min.)

L5. Remarks on the Problem of Superconductivity. R. P. FEYNMAN, *California Institute of Technology.* (30 min.)

FRIDAY MORNING AT 10:00

129 Founders Hall

(H. K. TICHO, presiding)

K-Mesons, etc.

M1. Proton-Proton Interactions at 5.3 Bev.* ROBERT W. WRIGHT, GEORGE SAPHIR,† WILSON M. POWELL, GEORGE MAENCHEN, AND WILLIAM B. FOWLER, *University of California, Berkeley.*—The cloud-chamber study of the interaction with protons of negative pions[1] and neutrons[2] at Bevatron energies has been extended to include proton-proton interactions. A 36-atmosphere hydrogen-filled diffusion cloud chamber operating in a pulsed magnetic field of 21 500 gauss is being exposed to a 5.3-Bev scattered proton beam from the Bevatron. Thirty-nine events have been obtained to date. Of these, six are elastic scatters, fourteen are inelastic scatters with two charged outgoing prongs, 16 have four charged outgoing prongs, two have six charged outgoing prongs, and one event has two charged outgoing prongs and an associated Λ^0. Thirty-one of these events, which occurred in a well-defined projected area in the cloud chamber, give 29.5±5.5 mb for the proton-proton total cross section at 5.3 Bev. The standard error is nearly all from statistical uncertainty.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Also at the University of San Francisco.
[1] Maenchen, Powell, Saphir, and Wright, Phys. Rev. **99**, 1619 (1955).
[2] Fowler, Maenchen, Powell, Saphir, and Wright, Phys. Rev. (to be published).

M2. Production of Unstable Particles in 4.5-Bev π^--p Collisions.* GEORGE MAENCHEN, WILLIAM B. FOWLER, WILSON M. POWELL, GEORGE SAPHIR,† AND ROBERT W. WRIGHT, *University of California, Berkeley.*—A 36-atmosphere hydrogen-filled diffusion cloud chamber was exposed to the 4.5-Bev negative pion beam from the Bevatron. Three events involving the production and subsequent decay of heavy unstable particles have been observed. In two of these events only one decay was seen. One of these is a Λ^0 which is produced together with a positive particle that appears, from its momentum and relative ionization, to be a K-meson. Another event contains two charged outgoing particles and a θ^0. The pions from the θ^0 can be measured quite well and yield a Q-value of 222.2±7.0 Mev. The third event is interpreted as the associated production of a θ^0 and a positive unstable particle, both of which decay before leaving the chamber. Visual estimates of the relative ionization of the positive particle and its proper time of flight of 1 to 2×10^{-10} sec favor its interpretation as a Σ^+ rather than a K^+. The decay product of this particle cannot be identified.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Also at the University of San Francisco.

M3. Masses of Positive K-Particles. I. Identification of K-Particles and Analysis of Secondaries. FRANCES M. SMITH, HARRY H. HECKMAN, AND WALTER H. BARKAS, *University of California, Berkeley.*—Our program on the measurement of meson masses has now been extended to include several types of K^+-mesons produced by the Bevatron and detected in emulsion. In order to identify the types of K^+s involved, the secondaries were analyzed in terms of grain density, range, and multiple scattering. The τ mesons are easily identified from the three charged pion daughters. The ranges in the emulsion of these secondaries are being measured to obtain an energy spectrum of the secondaries and a Q-value for the decay process. This is of particular value as we have carefully determined the density of the emulsion used in this study. We are also completing an experimental determination of the range-momentum relation in the emulsion as a part of the program. The τ'-mesons and $K_{\mu 3}$-particles included in the study were identified by following the secondary to the end of its range. These secondaries have grain densities substantially above minimum and thus have a high probability of stoping in the emulsion stack. Measurement of their ranges enables one to obtain the energy spectra of the secondaries from the τ' and $K_{\mu 3}$. The grain density at the beginning of the track of the $K_{\mu 3}$ daughter is about 1.05 minimum while that of the $K_{\nu 2}$ is about 1.20 minimum. A reasonable separation was obtained by grain-counting those secondary tracks whose "dip" angles were less than 15°.

M4. Masses of Positive *K*-Particles. II. Method, Analysis, and Results.* HARRY H. HECKMAN, FRANCES M. SMITH, AND WALTER H. BARKAS, *University of California, Berkeley.*—*K*-particle masses were measured by comparing ranges of $K_{\mu 2}$, $K_{\tau 2}$, $K_{\mu 3}$, and τ' mesons with the ranges of τ mesons and protons of the same momentum. For the momentum analysis we have used the Kerth-Stork arrangement, introducing several modifications that enabled us to obtain a mass resolution of 1.6% for an individual particle. The mesons were produced by bombarding a Ta target with 4.8-Bev protons. They had a flight time of about 1.2×10^{-8} sec before entering the detector, a stack of nuclear track emulsions. The scanning procedure was to traverse the emulsion 1.5 cm from the calculated depth of penetration for τ mesons, and to follow particles that fulfilled criteria of grain density and direction to the ends of their ranges. The data recorded for each *K*-particle included the mode of decay, the range (measured along the track), and the position of entrance into the stack. The mass differences of the *K*-mesons were calculated from the differences in the mean ranges of each type of particle. We have obtained the following masses, in units of the electron mass, when the mean of the τ mass is taken to be 966: $\tau(966\pm3.1)$, $K_{\mu 2}(962.5\pm3.2)$, $K_{\tau 2}(972.2\pm4.7)$, $K_{\mu 3}(951.2\pm10.6)$, $\tau'(951.5\pm10.9)$. If the particles are compared directly with protons of the same momentum, the masses are in close agreement with those measured relative to the τ mass.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

M5. Negative *K*-Particle Interactions in Nuclear Emulsion. I.* CHARLES E. VIOLET, F. C. GILBERT, AND R. STEPHEN WHITE, *University of California, Berkeley and Livermore.*—An emulsion stack, composed of 112 Ilford G. 5 emulsions 6 by 6 in. by 600 microns, has been exposed to a beam of magnetically analyzed negative *K*-particles produced at the Berkeley Bevatron. The momentum interval subtended by the stack extended from 280 to 400 Mev/c. The methods of exposure, processing, and labeling the stack will be described. Emulsions were systematically scanned for tracks fulfilling certain selection criteria which will be discussed. The observed negative *K*-particle interactions will be summarized.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

M6. Negative *K*-Particle Interactions in Nuclear Emulsion. II.* F. C. GILBERT, CHARLES E. VIOLET, AND R. STEPHEN WHITE, *University of California, Berkeley and Livermore.*—Interactions of about 75 negative *K*-particles that came to rest in the emulsion stack described in the preceding abstract have been analyzed. Prong distributions, π-meson ratios, Σ-particle ratios, unstable heavy particles, energy distributions, and other related properties will be given. The results will be compared with those of other groups working on this problem.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

M7. Negative *K*-Particle Interactions in Nuclear Emulsion. III.* R. STEPHEN WHITE, F. C. GILBERT, AND CHARLES E. VIOLET, *University of California, Berkeley and Livermore.*—Data concerning the interactions in flight of the negative *K*-particles listed in the two preceding papers will be discussed. From a measurement of the negative *K*-particle time of flight an estimate of the lifetime will be given. Individual negative *K*-meson interactions and Σ-hyperon decays and interactions of interest will be discussed. A value of the positive Σ mass which is based on the range of the decay secondary will be given. The results will be compared with those of other groups investigating the properties of negative *K*-particles.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

M8. One Hundred Bevatron $\tau^{+,0}s$.* ROY HADDOCK, *University of California, Berkeley* (introduced by D. H. Stork).—The decays of 100 $\tau^{+,0}$'s found during systematic scanning of 3 emulsion stacks exposed to a magnetically separated K^+-beam at the Bevatron have been analyzed. The ranges of the π's were measured along the track. On the basis of Barkas's[1] range-energy relation the average Q was 75.20 $\pm$0.12 Mev. The distributions in the π^- energy and the angle θ (angle between the relative momentum of the two $\pi^{+,0}$'s and the momentum of the π^-) have been compared by an χ^2 test with the theoretical relativistic distributions given by Fabri.[2] The cases for which a τ and a χ could be the same are excluded for spin less than 4. Of the remaining cases 1^+ is excluded and 0^-, 2^-, 3^+ can be fit satisfactorily. The decay plane normals were computed and the distributions appeared to be isotropic.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] W. H. Barkas and D. M. Young, "Emulsion tables. I. Heavy-particle functions," University of California Radiation Laboratory Report No. UCRL-2579 (rev).

[2] E. Fabri, Nuovo cimento **11**, 479 (1954).

M9. Mass Values of Identified *K*-Mesons.* JAMES R. PETERSON, *University of California, Berkeley.*—The charged decay products of positive *K*-mesons have been identified, and the masses of the primaries measured by the momentum-range method.[1] The *K*-mesons were found in two nuclear emulsion stacks (meson energies of 170 and 114 Mev) after exposure behind the strong-focusing magnetic spectrometer at the Bevatron with incident proton energies of 5.7 and 6.2 Bev. Decay modes of mesons other than τ's were established by either (a) following the secondary to the end of its range (*20* $K_{\mu 2}$'s and *20* $K_{\tau 2}$'s), (b) estimating the relative ionization by blob count at a considerable distance from the point of decay, or (c) measuring the relative ionization at the decay point. Reliable ratios of the frequencies of occurrence of various modes of decay have been obtained and are $K_{\mu 2}:K_{\tau 2}:\tau=100:56:12$ (τ includes alternate modes of decay), while the $K_{\mu 3}$ and K_{e3} each account for several percent of the total. Masses of the mesons are all consistent with that of the tau within a few electron masses. The data were obtained from about 200 events systematically selected from a total of some 1600 *K*-mesons.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] Birge *et al.*, Proceedings of the International Conference on Elementary Particles held in Pisa, Italy, in June, 1955 (to be published in *Il Nuovo Cimento*).

M10. Photometric Mass Determinations in a Multiplate Cloud Chamber.* DAVID O. CALDWELL AND YASH PAL, *M.I.T.*—A projection-type photometer has been adapted for measuring the opacity of multiplate cloud-chamber tracks. The ionization of a track may be determined by comparing its opacity with that of a track of known ionization in the same part of the chamber and in the same picture, or one taken under similar conditions. The ionization may be used to find the particle's range, or if the range is known, its mass measurements on a "negative proton" will be reported. For range measurements on identified particles, one needs to determine only the change in track opacity occurring when a plate is traversed. A nomogram then gives the residual range from the amount of material traversed and the ratio of ionizations on each side of the plate. Ranges of $K_{\mu 2}$ and $K_{\tau 2}$ secondaries have been found to be about 78 and

44 g/cm² of copper, respectively; more precise ranges and masses will be given. By combining the ionization ratio and ionization comparison methods, both the range and mass of a particle may be measured.

* This work has been supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

M11. Anomalous V^0-Particles.* W. H. Arnold,† J. Ballam, M. Grisaru, C. McGrew, and W. H. Wyld, *Princeton University.*—From photographs obtained with the Princeton dual cloud chamber[1] 82 neutral V-events have been found for which Q-values could be calculated. Out of these there were 30 Λ^0 and 31 θ^0 and 21 which could be either. In addition there were 5 events which are considered as anomalous in the sense that the Q-value calculated on the basis of either $\Lambda^0 \rightarrow p+\pi^-+37$ Mev[2] or $\theta^0 \rightarrow \pi^+ + \pi^- + 214$ Mev[3] actually deviates from either of these two values by three or more standard deviations. The data on these individual events will be presented. The Q-value for our Λ^0-events is 36±1 Mev and for the θ^0-events it is 212±4 Mev. If we assume that the anomalous events can be described by the decay $K^0 \rightarrow \mu^+ + \pi^0 + \nu$ then from the measured data the energy of the neutrino in the rest system of the K^0 can be calculated. This has been done for our and other published anomalous events. Results will be presented and compared with the "phase volume" distribution for this process.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

† Now with Westinghouse Electric Company, Pittsburgh, Pennsylvania.

[1] Hodson, Ballam, Arnold, Harris, Reynolds, and Treiman, Phys. Rev. **96**, 1089 (1954).

[2] Friedlander, Keefe, Menon, and Merlin, Phil. Mag. **45**, 333 (1954).

[3] Thompson, Burwell, Cohn, Hugget, Karzmark, and Kim, *Proceedings of the Rochester Conference* (Interscience Publishers, Inc., New York, 1954).

Friday Morning at 10:30

226 Founders Hall

(K. R. MacKenzie, presiding)

Cyclotrons and Scattering

N1. Theoretical Study of Relativistic Constant Frequency Cyclotrons.* David L. Judd, *University of California, Berkeley.*—A principle for circumventing relativistic effects limiting maximum energy of cyclotrons was discovered by L. H. Thomas and independently rediscovered by E. M. McMillan in 1949. On this was based an extensive program of theoretical investigation and calculation carried out by the author during 1950–1952. Greatest attention was paid to magnetic fields of the form $H_z(r=0) = (m_0\omega c/e)[1 + A(\omega r/c)\cos N\theta + B(\omega r/c)^2 + C(\omega r/c)^3 \cos N\theta + D(\omega r/c)^4 + \cdots]$, forming an extension of Thomas's work. The work was keyed to the model program described in the following abstract, for which $N=3$ was chosen to avoid resonances and simplify pole-tip shaping. An exact analytical scalar potential for the field above was obtained and found useful. Calculations included orbit shapes, "resonance condition" for equal periods, frequencies of radial and vertical betatron oscillations, energy limits, effects of a variety of field errors, and a "regenerative peeler"-type beam extraction scheme. Elctric field calculations were made for electrode systems of threefold symmetry driven by 3-phase rf power, including effects of electrical and mechanical misalignments, focusing effects, and details of pickup from arc sources at the center. The relationship of this work to more recent developments will be discussed, as will its application in modifying existing cyclotrons.

* The work was performed under the auspices of the U. S. Atomic Energy Commission.

N2. Electron Models of Relativistic Constant Frequency Cyclotrons.* Robert V. Pyle, Elmer L. Kelly, J. Reginald Richardson (*U.C.L.A.*), and Robert L. Thornton, *University of California, Berkeley.*—Two model c-w cyclotrons based on the principle of L. H. Thomas will be described. (The theory as extended by David L. Judd is discussed in the preceding abstract.) Both accelerated electrons to speeds about half that of light, in magnetic fields of threefold azimuthal periodicity. The first was used to test a number of accelerating electrode structures and methods of extracting the beam by means of modifications in the magnetic field. Nearly all of the circulating current could be collected outside of the machine and some progress was made toward focusing it into a single external beam. The second, a one-eighth scale model of a possible 300-Mev deuteron cyclotron, has a pole diameter of 40.5 inches, a central magnetic field of 19.3 gauss, and a minimum beam aperture of 1.3 inches. Three 60-degree wide, wedge shaped "triants" driven 120 degrees out of phase at 54.1 megacycles give a maximum energy gain per turn of 3 eV where V is the peak triant to ground voltage. Electrons have been accelerated without axial loss to $v/c=0.50$ (75 kilovolts) with $V=23$ volts. This "threshold" voltage corresponds to a triant voltage of less than 100 kv for the 300-Mev accelerator and is set by the geometry of the source structure rather than by the magnetic field.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

N3. Studies with a Three-Dee Three-Phase Proton Cyclotron.* Myron Heusinkveld,† Mark Jakobson,‡ Lawrence Ruby, Bob H. Smith, and Byron T. Wright,§ *University of California, Berkeley.*—As part of the program to investigate the properties of the cloverleaf cyclotron (see N1 and N2), a 20-in. diameter proton cyclotron was constructed. In such a three-dee three-phase system it is possible to accelerate protons, deuterons, and tritons at the same setting of frequency and magnetic field but on different modes of the rf. Three-phase rf was established on the 60° dees by a driven rf system. The signal originated at a crystal oscillator and the three phases were produced by a phase generator. It was necessary to employ servomechanisms in order to maintain the dees and final amplifier grids in tune. Interaction between the servos required neutralization of the inter dee capacitance by means of suitable transmission lines connected from dee stem to dee stem. The rf system maintained the phase of the dee voltages to within 1° of the desired 120° values. Under such conditions it was possible to attain steadily 6.0 ma of protons at 1.0 Mev in the forward mode and 6.5 ma of deuterons at 0.5 Mev in the reverse mode.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

† Now at the University of California Radiation Laboratory.

‡ Now at Montana State University.

§ Now at the University of California at Los Angeles.

N4. Elastic Scattering of 48-Mev Alpha Particles.* LARRY SCHECTER† AND R. E. ELLIS, *University of California, Berkeley.*—The angular distributions of 48-Mev alpha particles scattered elastically from Ag, Au, and Pb targets have been measured, using a proportional counter telescope as a detector inside a large evacuated scattering chamber. Deviations by three to four orders of magnitude from pure Coulomb scattering have been observed beyond the forward angles. In addition, some regular structure appears in these distributions, whose main features can be described by an exponential fall-off between 25° and 90°. By fitting the data with a simple modification of Blair's scattering theory, it has been possible to determine interaction radii. Nuclear radii have been derived which are in agreement with those found from medium-energy nucleon scattering.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Now at Oregon State College.

N5. Proton-Proton Scatterings at 19.6 Mev.* J. W. BURKIG, GLEN E. SCHRANK, AND J. REGINALD RICHARDSON, *University of California, Los Angeles.*—The differential scattering cross section for 19.8-Mev protons scattered from hydrogen has been measured at a number of angles ranging from 7° to 45° in the laboratory system of coordinates. The statistical accuracy of counting is ±1% for each point. The relative accuracy between points is ±1.5% as determined from the variation of a number of measurements at fixed angle. The absolute accuracy is estimated to be ±2.5%, this larger value being due to the presence of counts in the energy region below the scattering peak and to a low energy component of the beam of about 0.5%. The experiment was performed in a 30-in. scattering chamber filled with hydrogen, and using a scintillation counter and photomultiplier as a detector. Counting was done on either side of zero angle and the average used. Repeated measurements were made at several lower angles to check the accuracy of angular setting and for contamination of the hydrogen. In a second experiment (due to J.W.B. alone), using the same equipment, the $p-\alpha$ cross section was measured with a decreased statistical accuracy. These results will also be reported.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N6. Relative Stopping Power of Some Metallic Elements for 20-Mev Protons.* V. C. BURKIG AND K. R. MACKENZIE, *University of California, Los Angeles.*—The stopping power per electron relative to Al has been measured for 23 metallic elements from Be to Th with a probable error of 0.2% in most cases. The 20-Mev proton beam of the UCLA cyclotron was used with a differential ionization chamber as an energy-sensitive detecting device. An approximate straight line relationship was found as a function of ln Z with some deviations noted from Ta to Th and in the region of the filling of the 3d shell (Ca to Ni). Results are as follows: Be −1.166; Ca −0.982; Ti −0.936; V −0.918; Fe −0.886; Ni −0.872; Cu −0.867; Zn −0.866; Nb −0.816; Mo −0.809; Rh −0.800; Pd −0.793; Ag −0.791; Cd −0.789; In −0.782; Sn −0.782; Ta −0.715; W −0.706; Ir −0.703; Pt −0.695; Au −0.692; Pb −0.677; Th −0.691.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N7. Analysis of Elastic Scattering of 31.5-Mev Protons.* MICHEL A. MELKANOFF, JOHN NODVIK, AND DAVID S. SAXON, *University of California, Los Angeles.*—Recent experiments performed on the Berkeley linear accelerator have yielded differential cross sections for the elastic scattering of 31.5-Mev protons from about 20 elements throughout the periodic table.[1] We have analyzed this data[2] on the basis of the diffuse surface optical model of the nucleus.[3] The best fit with experiment is obtained with a complex potential depth of about $36+15i$ Mev for all elements heavier than say Fe (lighter elements show some fluctuations). This result may be compared with the value $45+8i$ Mev which has been found to give the best fit at 17 Mev.[4] The space dependence of the potential, however, is not significantly altered. Detailed comparisons between calculated and observed cross sections will be presented.

* Supported in part by the National Science Foundation, the Office of Naval Research, and the Office of Ordnance Research.
[1] We are indebted to B. T. Wright, B. B. Kinsey and J. Leahy, each of whom has furnished his results prior to publication.
[2] The calculations were performed on the SWAC, Numerical Analysis Research Project, Dept. of Mathematics, UCLA using the code prepared by R. D. Woods.
[3] R. D. Woods and D. S. Saxon, Phys. Rev. **95**, 577 (1954).
[4] To be published. See also UCLA Physics Dept. Technical Report 7-12-55.

N8. Small-Angle Proton-Proton Scattering at 20 Mev.* HERBERT N. ROYDEN AND BYRON T. WRIGHT, *University of California, Los Angeles.*—The differential cross section for the scattering of 19.8-Mev protons by protons has been measured for angles between 18° and 36° in the center-of-mass system, using photographic emulsions as detectors. The angular resolution was 0.6°. Cross sections were measured simultaneously at all angles and azimuths, one run with analyzing slits closed serving to evaluate the small slit-edge correction. The scattering chamber used was a modification of that described by Faris and Wright.[1] The external proton beam of the U.C.L.A. 20-Mev synchrocyclotron passed through a collimator and the scattering chamber, filled with hydrogen gas at one atmosphere, and was collected in a Faraday cup. The charge collected by the Faraday cup was measured with a 100% feedback electrometer which had been calibrated to 0.3%, using a current-time method.[2] A scintillation counter was used to monitor contaminants in the hydrogen gas. Results will be presented.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] F. E. Faris and B. T. Wright, Phys. Rev. **79**, 577 (1950).
[2] H. N. Royden and D. O. Caldwell, Rev. Sci. Instr. (to be published).

N9. Energy Loss of Protons in Metals.* R. E. PIXLEY, M. BADER, AND WARD WHALING, *California Institute of Technology.*—The rate at which protons lose energy in passing through thin evaporated layers of metal has been measured for protons in the energy range between 50 and 600 kev. The materials studied are Li, Be, Al, Cr, Mn, Fe, Co, Ni, Cu, Zn, Au, and Pb. Together with earlier measurements in this laboratory of the rate of energy loss in several gases, these results provide information about the variation of energy loss with the atomic number of the stopping material. For high energy protons, the energy loss per stopping atom increases smoothly with Z; the scattered results that are available are consistent with the theoretical $Z^{1/3}$ dependence. The influence of molecular binding on the stopping cross section of compounds becomes noticeable below 150 kev. For protons of 500 kev, a fairly uniform Z-dependence is apparent over most of the periodic table, but two types of deviation are still observed. First, the stopping cross sections of the noble gases are relatively lower than that of their neighbors. This effect can be understood in terms of the reduced energy loss to the more tightly bound electrons of closed shells. Second, in the region from $Z=23-29$, the stopping cross section decreases with increasing Z. With the exception of a high value at Cr, the decrease is fairly uniform from V through Cu.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 1:30

133 Founders Hall

(C. D. ANDERSON, presiding)

Invited Papers on Cosmic Rays and K-Mesons

O1. The Interaction of *K*-Particles from the Bevatron. G. GOLDHABER, *University of California, Berkeley.* (25 min.)

O2. Properties of Positive *K*-Mesons. D. H. STORK, *Radiation Laboratory, University of California.* (25 min.)

O3. *K*-Meson Counter Experiments. M. L. GOOD, *Radiation Laboratory, University of California.* (25 min.)

O4. Orgin of Cosmic Rays. L. DAVIS, JR., *California Institute of Technology.* (25 min.)

O5. Recent Experiments on Primary Cosmic Rays. E. P. NEY, *University of Minnesota.* (30 min.)

FRIDAY AFTERNOON AT 1:30

129 Founders Hall

(E. L. KINSEY, presiding)

Solid State II

P1. Compound Formation between Lithium and Boron Dissolved in Single Crystal Silicon. C. S. FULLER AND H. REISS, *Bell Telephone Laboratories.*—At high temperatures (above 800°C) the solubility of lithium in silicon doped with boron is considerably higher than in undoped silicon. The detection of this phenomenon is based on measurements of the resistivities of crystals saturated with lithium by diffusion. The increased solubility is not explicable in terms of the hole-electron mechanism developed previously.[1] A theory which fits the data quantitatively can be developed by assuming that lithium, boron, and a vacancy which has accepted an electron combine to form LiB^- complexes in which the lithium occupies an sp^3 position relative to the boron and is bound to it by a covalent bond. The reaction in favor of the complex is aided by the high concentrations of vacancies and conduction electrons available at higher temperatures.

[1] H. Reiss and C. S. Fuller, Phys. Rev. **97**, 559 (1955); also to be published in the *Journal of Metals.*

P2. Ionization of Hydrogen in Germanium and Silicon. HOWARD REISS, *Bell Telephone Laboratories.*—Considerable evidence exists that grown germanium and silicon crystals contain large amounts of dissolved hydrogen which do not appear to affect the semiconducting properties of the crystals.[1] The failure of hydrogen to ionize, when dissolved, is puzzling because lithium which, like hydrogen, is presumably interstitial possesses the lowest ionization energy of all known donors in germanium and silicon. A quantum-mechanical treatment of this anomaly reveals that the situation is consistent with theory. In pictorial terms the explanation is as follows. A lattice interstice may be regarded as a spherical cavity in a dielectric. An interstitial hydrogen, being small, fits entirely into the cavity while lithium is large enough to spill over into the surrounding dielectric. As a result the dielectric medium is *inside* the lithium atom and *outside* the hydrogen, reducing the ionization energy of the former and having a much less profound effect on the latter.

[1] O. H. Johnson, Chem. Revs. **51**, 431 (1952).

P3. Thermal Conductivity of Neutron-Damaged Graphite. NED S. RASOR AND JOHN E. HOVE, *North American Aviation, Inc.*—Graphite conducts heat by lattice waves and the thermal conductivity of the artificial pitch-bonded graphites exhibits an anomalous temperature dependence in that it is stronger than the temperature variation of the specific heat at low temperatures. This has been explained in terms of the two-medium nature of such graphites.[1,2] The present paper shows the effect of pile neutron exposure on the thermal conductivity of three types of artificial graphite with crystallite sizes of about 6000 A, 3000 A, and 300 A. In all cases, the values have been measured as a function of temperature from 15°K to 300°K. There is a large decrease in the magnitude of the conductivity (e.g., by a factor of five for the large crystallite graphite after being exposed to a fast flux of about 2×10^{18} nvt) while the temperature dependence of the thermal conductivity also changes with damage, but less strongly. These data have been analyzed on the basis of the two medium theory[2] by which the relative number of internal defects has been obtained as a function of neutron exposure and found to vary in an inverse manner with the crystallite size. The general behavior of the thermal conductivity with damage supports the basic theory very well.

[1] A. W. Smith, Phys. Rev. **98**, 1563(A) (1955).
[2] J. E. Hove, Phys. Rev. **98**, 1563(A) (1955).

P4. Magnetic Susceptibility of Neutron-Damaged Graphite.* JOHN E. HOVE, *North American Aviation, Inc.*—A recent paper[1] attempts to establish a quantitative theory of the magnetic susceptibility of graphite. The experimental results obtained from bromine-graphite residue compounds are used to verify the theory. The effect of introducing bromine into the graphite in this manner is to trap some of the conduction electrons and thereby alter the value of the diamagnetism. Similarly, one of the results of irradiating graphite in a reactor is the trapping of electrons. As expected, therefore, the diamagnetic susceptibility of damaged graphite is markedly decreased. The values of the total susceptibility (i.e., the sum of the susceptibilities measured

in three mutually perpendicular directions) of AGOT-KC graphite have been measured by J. D. McClelland (unpublished) at room temperature and at liquid nitrogen temperature as a function of integrated neutron flux. The interpretation of these data in terms of the above theory[1] yields two results of interest: (1) The quantitative theory is again verified and (2) a value of $1.4+10^{-4}$ electron (per carbon atom) trapped after 1.7×10^{17} nvt of fast neutrons is obtained for the rate of electron trapping with pile exposure. This agrees very well with that determined by use of the bromine-graphite residue compounds.

* Based on studies conducted for the U. S. Atomic Energy Commission.
[1] John E. Hove, Phys. Rev. **100**, 645 (1955).

P5. Stored Energy Release in Graphite Irradiated at Low Temperatures.* S. B. Austerman, *North American Aviation, Inc.*—Previous measurements of electrical and thermal resistivities and paramagnetic resonance have shown that graphite, when irradiated near liquid nitrogen temperature, retains considerable damage which anneals out below room temperature. This report deals with the release of stored energy associated with this damage. To compute stored energy release, the relative specific heat of an irradiated specimen is compared with that of the specimen after annealing. Various types of artificial and natural graphite were irradiated in the liquid nitrogen facility of the Brookhaven reactor. The stored energy release spectrum during steady temperature rise shows a peak at 215°K for graphite having large crystallites (3000 A length) and about 185°K for fine-crystallite graphite (300 A length). If the defects are assumed to diffuse out of the crystallites on heating, the dependence of the annealing behavior on crystallite size can be accounted for with an activation energy of about 0.4 ev. The total stored energy releasable below 275°K accumulates linearly with neutron exposure at a rate of 1.4 cal/g per 10^{18} nvt. By estimating the number of responsible defects from neutron scattering data, the stored energy per atomic displacement is found to be of the order of 2 ev. An apparent increase in specific heat appears at low temperatures and can be qualitatively accounted for on the basis of isolated interstitial atoms behaving as Einstein oscillators.

* This work supported by the U. S. Atomic Energy Commission.

P6. Ion Pairing Involving Lithium in Germanium and Silicon. F. J. Morin, Howard Reiss, and C. S. Fuller, *Bell Telephone Laboratories.*—The formation of ion pairs involving the donor lithium and the acceptors boron and gallium, has been observed experimentally in the semiconductors silicon and germanium. Several methods of observation have shown the effect. Measurements of the diffusion coefficient of lithium revealed a reduction in diffusivity as pairing occurred. Measurements of the mobilities of carriers in the ionized impurity scattering region showed large changes as pairing removed scatterers. Observation, by Hall effect, of energy diagrams showed alterations of the impurity levels in the presence of pairing. In germanium it is found that the pair distributions relax towards equilibrium at temperatures as low as 100°K. At such temperatures very complete pairing occurs even when the impurities are present in traces, e.g. 10^{15} atoms per cm^3.

P7. Effect of Low-Temperature Electron Irradiation on the Electrical Resistivity of Copper.* C. J. Meechan, *North American Aviation, Inc.*—High purity copper has been irradiated at −196°C with 1.25-Mev electrons. The electrical resistivity (ρ) was measured (1) as a function of exposure (ϕ) during the irradiation and (2) as a function of annealing temperature following the irradiation. An initial curvature was observed in the ρ *vs* ϕ curve up to approximately 6×10^{17} electron/cm^2. From this point, up to at least 3×10^{18} electron/cm^2, the exposure curve is linear. The slope of this linear portion of the curve was $4.24+10^{-22}$ ohm-cm per electron/cm^2. Approximately 50% of the induced resistivity change recovers in a well-defined state centered at 25°C. About 30% of the damage recovers at lower temperatures. The remaining 20% begins to recover at 125°C and all of the damage was removed at 300°C.

* This work performed under contract for the U. S. Atomic Energy Commission.

P8. A New Method for the Determination of Activation Energies.* J. A. Brinkman, *North American Aviation, Inc.*—A new procedure for obtaining and analyzing data for the purpose of determining activation energies governing the recovery of the physical property changes of damaged solids has been developed. For situations in which the method is applicable, it generally yields greater accuracy and is frequently more convenient to use than other methods. If a general recovery equation of the form, $d\rho/dt=F(\rho)\exp(-E/kT)$, is assumed, where ρ is the measured property, two initially identical specimens are required for the determination of the activation energy, E, by this method. An isothermal annealing curve is obtained by annealing the first specimen at a constant temperature and measuring ρ as a function of time. A tempering curve is obtained by heating the second specimen to successively higher temperatures for equal time intervals and measuring ρ after each such temperature pulse. If an equation of the form, $d\rho/dt=-\nu\rho^\gamma\exp(-E/kT)$, is assumed, only the tempering curve is needed to determine E; thus one specimen is sufficient. Application of the method to the 25°C recovery state described in the preceding abstract yielded an activation energy of 0.63 ev and a value of 2.5 for γ in the above equation.

* This work performed under contract for the U. S. Atomic Energy Commission.

P9. Influence of Lattice Defects on the Young's Modulus of Copper.* H. Dieckamp, *North American Aviation, Inc.*—The Young's modulus of copper has been measured as a function of energetic electron flux. Relative measurements of the Young's modulus of 99.999% purity copper were made by observing the driven resonant frequency of a cantilever beam during bombardment with 1-Mev electrons at a temperature below −50°C. The modulus is observed to increase with the change saturating at an increase of about 1 to 2% after an exposure of about 10^{18} electrons/cm^2. A model involving the pinning of dislocations by interstitials and/or vacancies seems to be appropriate. The introduction of such a model into the result of Mott for the dislocation contribution to Young's modulus, $\Delta E/E=1/6N\beta^2$, yields a flux dependence of the modulus which fits the experimental data. The choice of an appropriate value for the probability of producing a pinning point allows the theory to yield reasonable values for the number and average length of dislocations in a sample.

* This work performed under contract for the U. S. Atomic Energy Commission.

P10. Field Dependence of the Hall Potential and Magnetoresistance of Irradiated Graphite.* J. D. McClelland, *North American Aviation, Inc.*—The magnetic field dependencies of the Hall potential and magnetoresistance have been determined for a series of irradiated artificial graphite samples. Measurements were made at room temperature at fields between 5 and 15 kilogauss. Irradiations ranged up to an integrated fast neutron flux of 2×10^{19} nvt. The Hall coefficient changes from a value of −0.66 emu for the

unirradiated sample to +0.86 for the most highly damaged sample. In all cases the absolute value of the Hall potential increased linearly with field and extrapolated to zero at zero field. Over the range of magnetic field studied the magnetoresistance can be expressed as $(\Delta R/R)=AH^{n}$. At a field of 10 kilogauss the value of $\Delta R/R$ fell from a pre-irradiation value of 2×10^{-3} to 7×10^{-4} for the highly damaged specimen. At the same time the exponent of H increased with exposure from 1.77 to 1.88. Thus, with neutron damage, the magnetoresistance of graphite appears to approach the behavior typical of a good metal, both in absolute value and in field dependence. The reasons for this will also be discussed.

* This work performed under contract for the U. S. Atomic Energy Commission.

P11. Thermal Conductivity of Superconducting Lead below 1°K. B. R. Felix, L. Passell, and H. B. Silsbee, *University of California, Berkeley.*—The thermal conductivity of single crystals of high purity lead has been measured from 0.15°K to 0.8°K in the superconducting state. The electronic contribution should be negligible in this region, while the lattice conductivity is expected to follow the prediction of Casimir.[1] The experimental temperature dependence is as $T^{2.7\pm0.2}$, i.e, faster than the T^{3} to be expected from the specific heat, and the magnitude of the conductivity is appreciably smaller than predicted. The results suggest a scattering mechanism for phonons for which the cross section increases with decreasing temperature. A speculative explanation of the results will be offered.

[1] Casimir, Physica **5**, 495 (1938).

P12. Thermal Conductivity of Aluminum at Low Temperatures. L. Passell, B. R. Felix, and H. B. Silsbee, *University of California, Berkeley.*—The thermal conductivity of pure polycrystalline aluminum has been measured in its normal state from 1.3°K to 3.5°K and, by adiabatic demagnetization techniques, in its superconducting state from 0.3°K to 0.8°K. The high Debye temperature of aluminum makes the lattice conduction negligible compared to the electronic contribution. If the normal results are extrapolated to the lower temperature range, the ratio of the superconducting to the normal conductivity may be plotted as a function of reduced temperature, T/T crit. The points thus obtained can be combined with previous results[1,2] for the electronic conductivity which may be compared with theory.

[1] Hulm, Proc. Roy. Soc. (London) **A204**, 98 (1950).
[2] Goodman, Proc. Phys. Soc. (London) **A66**, 217 (1953).

P13. Transverse Field Effects in PbS. D. E. Martz and R. S. Witte, *U. S. Naval Ordnance Test Station.*—Recent investigations on commercial lead sulfide cells have revealed that large changes in resistance, time constant, and sensitivity can occur when the cells are subjected to dc electric fields that are directed normal to the surface of the layer. A field directed from the substrate to the layer gives rise to an initial increase in layer resistance followed by a long term (days) decrease to a very low value. Typical values of the initial resistance, peak resistance, and final equilibrium value are 1.0 megohms, 100 megohms, and 1000 ohms, respectively. The rate of change in resistance is approximately proportional to the applied field and is strongly temperature dependent. In producing these changes, a metal film is either evaporated or painted onto the underside of the glass substrate and voltage is applied between this backing and the layer. The changes are not observed if a thin insulating layer is placed between the metallic back and the glass. A two-step mechanism is postulated. The field introduces ions from the glass into the layer and these ions then distribute themselves throughout the layer by means of thermal diffusion.

Friday Afternoon at 1:30

226 Founders Hall

(R. Feynman, presiding)

Theory

Q1. An Alternative Interpretation of Magnetic Forces between Moving Charges. John Backus, *University of Southern California.*—Magnetic interactions of charges are usually described in terms of a force between a charge in motion (relative to an assumed reference system) and another charge in motion. It will be shown that magnetic forces may be interpreted in terms of moving charges exerting forces on charges at rest, i.e., as forces acting on charges in relative motion. If charge q_1 is moving with a velocity $\mathbf{v}$ relative to charge q_2, and $\mathbf{r}$ is the vector from q_1 to q_2, then if a force $\mathbf{f}_2$ (in addition to the Coulomb force) is assumed to act on q_2, the usual formulas for the magnetic interactions of circuits will result if $\mathbf{f}_2=-q_2\nabla\phi$, where, in mks units, $\phi=-(\mu_0 q_1/16\pi)\{[3(\mathbf{v}\cdot\mathbf{r})^2/r^5]-(v^2/r)\}$.

Q2. Generalized Theory of Mobility. Melvin Lax, *Bell Telephone Laboratories and Syracuse University.*—In the presence of strong interaction between an electron and a scattering system it is difficult, if not impossible, to decompose the Hamiltonian of the electron plus scattering system uniquely into an unperturbed portion (describing the renormalized electron) and a perturbation. Furthermore, the time between scatterings may be short compared to the characteristic times of the scattering system, so that we no longer have a succession of independent scattering events with no phase relations between them, i.e., a Boltzmann transport equation may be meaningless. A theory has therefore been developed that omits the customary assumptions and treats only the electric field as a perturbation. The resulting mobility is $\mu=e\tau/m$ where the (tensor) relaxation time τ is given by $i\hbar\tau=\int_{-\infty}^{0}\exp(i\omega t)\ \mathrm{trace}\,[\mathbf{r}(t),\mathbf{p}]\rho_0]dt$, where $\mathbf{r}(t)$ is the Heisenberg position of the electron $\exp(iHt/\hbar)\cdot\mathbf{r}\exp(-iHt/\hbar)$ and ρ_0 is the thermal equilibrium density matrix $\exp(-\beta H)/\mathrm{trace}\,[\exp(-\beta H)]$, with $\beta=(kT)^{-1}$ and H is the total (undecomposed) Hamiltonian of the electron-lattice system. A generalized Nyquist theorem will be given that relates both the real and the imaginary part of the conductivity $\sigma(\omega)=ne^2\tau/m$ to the current fluctuations.

Q3. A Schrödinger-Like Equation for the Measurement Process. Richard Scalettar, *University of Southern California.*—It has been shown[1] that, if ρ_b and ρ_a are the density matrices before and after an ideal measurement and E is the measurement projection operator, then $\rho_a=E\rho_b E$. If a se-

quence of measurements, $E(t_j)$, is performed at times $t_j = j\epsilon (j=0, 1, 2, \cdots)$ and in the time intervals, ϵ, between measurements, the system propagates undisturbed with a time-independent Hamiltonian, H, then the probabilistic behavior at time t_n is given by the state vector,

$$|\psi(t_n)> = E(t_n) \exp\left(-\frac{i}{\hbar}\epsilon H\right)|\psi(t_{n-1})>.$$

It follows that, if the measurement process is continuous in a sense to be defined precisely,

$$\left\{E(t)H - \frac{\hbar}{i}\frac{dE(t)}{dt}\right\}|\psi(t)> = -\frac{\hbar}{i}\frac{d|\psi(t)}{dt}>,$$

a Schrödinger-like equation for the ideal measurement process. (It is assumed that ρ is initially pure.) The physical significance of this result, its relation to the question of reversibility, and an application to Feynman's statistical assertions[2] will be discussed.

[1] G. Ludwig, *Die Grundlagen der Quantenmechanik* (Springer-Verlag, Berlin, 1954).
[2] R. P. Feynman, Revs. Modern Phys. **20**, 367 (1948).

Q4. Variational Methods in Scattering Problems.* MILDRED M. MOE AND DAVID S. SAXON, *University of California, Los Angeles.*—The application of variational methods to scattering problems has been limited by (a) the complexity of the integration required in the use of the Schwinger formulation[1] even for the simplest trial functions, and (b) the difficulty of finding adequate trial functions in the relatively simple Kohn formulation.[2] We have slightly modified the latter by setting the trial function equal to the incident wave plus a correction term and then rewriting the variational principle in a form independent of the amplitude of the correction term. In this form, any trial function can immediately be generalized using finite sets of partial waves as previously reported in connection with the Schwinger formulation. We have also examined the relation between the Kohn formulation in terms of phase shifts and in terms of the total scattering amplitude. As a result we have been led to the view that the variational principles for scattering can be formulated in an enormous variety of ways none of which can be selected *a priori* as preferable to any other. Possible criteria for a choice are being sought.

* Supported in part by the National Science Foundation.
[1] B. F. Lippman and J. Schwinger, Phys. Rev. **79**, 469 (1950).
[2] W. Kohn, Phys. Rev. **74**, 1763 (1948).

Q5. Polarization Effects in Electron-Photon Interactions. CRAMER SCHULTZ AND ROSS D. F. THOMPSON, *University of Southern California.*—This paper discusses the means of detecting the circular polarization states of gamma rays. It is shown that an analysis of Compton scattering, using a method suggested by Halpern, offers the most effective means of determining the polarization. In addition, other experiments to detect circular polarization are discussed.

Q6. Radiative Corrections to Decay Processes.* R. E. BEHRENDS, R. J. FINKELSTEIN, AND A. SIRLIN, *University of California, Los Angeles.*—Radiative corrections associated with the electromagnetic field have been determined for the decay of a fermion of arbitrary mass into a lighter one with the emission of a single boson or of two other fermions; no special assumptions have been made about the nature of the interaction responsible for the instability. The particular example of the muon-electron decay has been worked through in detail. Sufficiently accurate experimental determination of the muon spectrum would permit the observation of a Lamb effect without vacuum polarization. Modified formulas for the Michel parameter ρ are given. The experimental results of Lederman *et al.*[1] are modified by this correction from ρ exp$=0.64\pm0.10$ to 0.68 ± 0.10. In addition the ρ values of the various proposed Fermi interactions are slightly altered. For example, the ρ of $S-T+P$ is decreased from 0.75 to 0.727.

* This work was supported in part by the National Science Foundation.
[1] L. Lederman (private communication).

Q7. Photoproduction of π-Meson Pairs in Hydrogen. F. ZACHARIASEN, *M.I.T.* (introduced by S. D. Drell).—The reaction $\gamma+p \rightarrow p+\pi^++\pi^-$ has been studied in the Chew-Low formalism,[1] assuming a linear P-wave meson-nucleon coupling and no meson-meson interaction. It is found that in the low-energy region, where the production consists primarily of S- and P-wave mesons, the cross section for this process can be related exactly to the experimental meson-nucleon scattering phase shifts. In this region the pair production comes almost entirely from the $\sigma \cdot \mathbf{A}\tau \cdot \boldsymbol{\phi}$ coupling, only 10 to 15% being contributed by the meson current. The cross section obtained here seems to be consistent with existing experimental evidence.[2] Experimental information on the π-pair production in the energy region threshold to almost 500 Mev will then produce information on the size of the meson-meson interaction (of S- and P-wave mesons).

[1] G. P. Chew and F. E. Low, private communication.
[2] M. L. Sands, private communication.

Q8. Some Remarks on Strangeness. S. EPSTEIN, *University of Nebraska.*—We consider couplings of the form (baryon)(baryon)′(meson) between the baryons Ξ, Σ, Λ, and N, and the mesons θ, θ, and π, and try to determine the minimum physical requirements which must be imposed so that the resultant classification of couplings as strong or forbidden agrees with the strangeness rules.[1] Our results may be stated as follows. There are several classifications consistent with the requirements that (A) hyperons and mesons should be stable against π emission and (B) that in π-N collisions any of the hyperons can be produced in association with one or more heavy mesons, the nature of the latter being subject to the restriction (C) that it be impossible to convert two nucleons into two hyperons. The strangeness classification is then distinguished by the fact that it alone then permits Σ and Λ particles to be produced in association with but one positive heavy meson. We will also comment on the fact that with this model any reaction which conserves strangeness can be realized by a sequence of strong couplings.

[1] M. Gell-Mann, Phys. Rev. **92**, 833 (1953); T. Nakano and K. Nishijima, Progr. Theoret. Phys. Japan **10**, 581 (1953).

Q9. Difference in Lifetimes of θ^0 and θ^+ Mesons.* S. OKUBO AND R. MARSHAK, *University of Rochester.*—The lifetime of θ^0 is approximately 100 times shorter than that of θ^+. Dalitz[1] has suggested one possible explanation of this difference (assuming that θ is scalar) by remarking that the $\theta^0 \rightarrow \pi^++\pi^-$ decay is compatible with the selection rule $\Delta I = \pm 1/2$ (I is the isotopic spin) whereas $\theta^+ \rightarrow \pi^++\pi^0$ requires $\Delta I = \pm 3/2$ and therefore may be more strongly forbidden. We have examined an alternative explanation by postulating a strong pion-pion attraction in the appropriate $I=0$ state but not in the $I=2$ state. The parameters of the pion-pion attractive potential are determined by invoking the conjecture of Piccioni, Dyson,[2] and Takeda that it is the same interaction which is responsible for the second maximum in the negative pion-proton scattering cross section. The effect on the θ^0 lifetime is sensitive to the assumed range of the pion-pion potential. If the range is the nucleon Compton wavelength, it appears possible to reconcile the θ^0 and θ^+ lifetimes.

If the range is closer to the pion Compton wavelength, the present explanation seems insufficient.

* Supported in part by the U. S. Atomic Energy Commission.
† Private communication.
‡ See F. J. Dyson, Phys. Rev. **99**, 1037 (1955).

Q10. Remarks on the Anti-Proton.* T. Regge, S. Okubo, and R. Marshak, *University of Rochester.*—There is a striking resemblance between the K-meson pair production mechanism at Cosmotron energies and the proton pair production at Bevatron energies. This analogy is utilized to estimate the anti-proton yield at 6 Bev from the measured K^--yield at 3 Bev.[1] The annihilation reactions $\bar{p}+p \rightarrow K^+ + K^-$ or $K^\circ + \bar{K}^\circ$ conserve the "strangeness" quantum number so that they should *a priori* compete favorably with the reactions $\bar{p}+p \rightarrow \pi^+ + \pi^-$ or $2\pi^\circ$.[2] Estimates of the relative annihilation cross sections have been made up to 500 Mev kinetic energy for the incident antiproton, considering both scalar and pseudoscalar K-mesons. Finally, the hypothesis of a strongly bound state of the proton-antiproton system[3] (called nucleonium) has been examined for its bearing on the production and annihilation processes involving antiprotons. In particular, estimates are made of the relative production cross section for nucleonium and the relative cross section for the one pion annihilation reaction which it makes possible.

* Supported in part by the U. S. Atomic Energy Commission.
† E. O. Salant (private communication).
‡ Multiple pion emission is also possible, even likely; multiple K-meson emission is rather improbable.
§ M. Lévy and R. Marshak, Nuovo cimento Supplem. No. 2, 253 (1954).

Q11. Wave Equations for Arbitrary Spin. C. Fronsdal, *University of California, Los Angeles.*—A method is presented for deriving wave equations for particles of arbitrary spin, without subsidiary conditions. The equations obtained are equivalent to that of Dirac, for spin $\frac{1}{2}$, and to that of Fierz for spin 3/2. The equations are not all of the first order, but of orders $2s$ in the operator p.

SUPPLEMENTARY PROGRAMME

SP1. Electron Spin Resonance of Impurities in Magnesium Oxide.*† John E. Wertz, Juana L. Vivo, and Boris Musulin, *University of Minnesota.*—All magnesium oxide crystals we have been able to locate show a six-line hyperfine splitting pattern found previously upon deliberate addition of manganese.[1] Technical MgO powder shows the same behavior as does also a reagent grade which has been heated to 1200°C. Their line width is as small as 1.5 gauss, very narrow for an ionic crystal, and much narrower than found previously.[1] The fourth line (counting from the low-field end) shows unusually large variations of intensity relative to the other five. Each of the principal lines has four satellites, explainable for an electronic spin of 5/2. At high spectrometer sensitivity, a number of weak lines are found in pairs. Their origin is being investigated. Heating to 200°C in the resonant cavity of the spectrometer decreases the ESR line intensity by an amount expected from Curie's law. An impurity of nuclear spin 7/2 and electronic spin 3/2 gives eight principal lines over a 560 gauss region. Each has two satellites.

* Supported in part by the Air Force Office of Scientific Research.
† To be given at the end of Session B if the chairman rules that time permits.
‡ W. D. Hershberger and H. N. Leifer, Phys. Rev. **88**, 714 (1952).

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